Good Practice

Guide 60

The Application of Combined Heat and Power in the UK Health Service

Energy Efficiency Office

DEPARTMENT OF THE ENVIRONMENT

BEST PRACTICE PROGRAMME

THE APPLICATION OF COMBINED HEAT AND POWER IN THE UK HEALTH SERVICE

This booklet is No. 60 in the Good Practice Guide Series and is designed to offer management guidance, technical advice and information on the application of Combined Heat and Power (CHP) installations in the UK Health Service. It is intended to help in the evaluation of the costs and benefits of installing CHP equipment on a Health Service site.

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Other titles in the Good Practice Guide Series

1. GUIDANCE NOTES FOR THE IMPLEMENTATION OF SMALL-SCALE PACKAGED COMBINED HEAT AND POWER
2. GUIDANCE NOTES FOR REDUCING ENERGY CONSUMPTION COSTS OF ELECTRIC MOTOR AND DRIVE SYSTEMS
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FOREWORD

This guide is part of a series produced by the Energy Efficiency Office under the Best Practice programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded boxes for easy reference:

— ***energy consumption guides:*** (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— ***good practice guides and case studies:*** (red) independent information on proven energy saving measures and techniques and what they are achieving;

— ***new practice projects:*** (green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— ***future practice R&D support:*** (purple) help to develop tomorrow's energy efficiency good practice measures.

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ENDORSEMENT BY THE DEPARTMENT OF HEALTH

The NHS is committed to achieving a new energy saving target of 15% over the next five years. In addition to meeting this challenge, health authorities and NHS Trusts are also looking at further ways of contributing to environmental protection. One specific technology which can make a significant contribution to both these endeavours is the introduction of Combined Heat and Power (CHP) systems.

I welcome very much the opportunity to commend to you this Good Practice Guide, which complements the strategic guidance published by NHS Estates on behalf of the Department of Health and builds on experiences of various sites within the NHS. CHP is an evolving technology and no two sites will display the same energy needs and opportunities for such installations. The range of options presented in this Good practice guide will be of considerable help in the selection of suitable schemes.

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COMBINED HEAT AND POWER IN THE HEALTH SERVICE

1. INTRODUCTION TO GUIDE

This Good Practice Guide (GPG) offers management guidance, technical advice and information on the application of Combined Heat and Power (CHP) installations on Health Service sites. The Guide is specific to the Health Sector and is intended to complement the other CHP Guides in this series (GPG's **1**, 3 and **43**).[1]

The guide is primarily aimed at the installation of purpose-built CHP equipment in existing hospitals[2], although it also covers designing CHP into new hospitals. It should be of interest and practical help to managers, technicians and engineers involved in the design, construction, use, operation or maintenance of building services and equipment, technicians and their managers. The guidance offered is intended to help management to evaluate the costs and benefits of installing CHP equipment on suitable Health Service sites, and to encourage its introduction.

Electricity is expensive when compared with other sources of energy for a hospital site, such as coal, oil and gas. This is because when electricity is generated at a conventional power station only 30% of the primary energy is delivered to the consumer as electricity.

By contrast, CHP recovers around 80% of the primary energy in a useful form. It brings the generating plant onto the hospital site, where the waste exhaust gases and cooling water can be used directly to produce hot water and/or steam. CHP does not reduce the total energy requirements of a particular site, but, by optimising the use of primary energy, both in terms of electricity and heat, it reduces overall energy costs and the amount of fuel used.

Correctly designed and installed CHP can provide valuable energy cost savings. Few hospital sites in the UK are totally unsuitable for some form of CHP, and it is recommended that every hospital should consider its introduction.

The information in this guide is arranged in the following sections:

- **Section 2 - CHP in the Health Care Environment**

  This section introduces the main benefits and potential pitfalls associated with CHP together with a strategy for CHP in the Health Service. It reviews the impact of CHP on other hospital engineering services and examines the environmental implications.

  Environmental issues are becoming increasingly important and hospitals are expected to set an example by minimising emissions which are hazardous to health resulting from their activities, as well as by showing a responsible approach to the utilisation of natural resources. Implementation of CHP can contribute to both these objectives.

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1 GPG **1**: 'Guidance Notes for the Implementation of Small-scale Packaged Combined Heat and Power'.
GPG **3**: 'Introduction to Small-Scale Combined Heat and Power'.
GPG **43**: 'Introduction to Large-Scale Combined Heat and Power'.

Copies of these publications are available from ETSU's Energy Efficiency Enquiries Bureau (Tel. No: 0235 **436747**).

2 For the purpose of this guide, 'hospital' refers to all health care organisation sites, including NHS, Trust and Private hospitals.

- **Section 3 - The Application of CHP**

  This section examines the issues associated with CHP[3] and the provision of standby power, two issues that are linked but require separate consideration in the first instance, to avoid any misunderstanding of the different objectives of CHP and/or standby power. The main components of a CHP plant are examined, together with descriptions of the common types of system suitable for hospital use. The importance of heat to power ratios are explained.

- **Section 4 - Technical Appraisal**

  This section emphasises the importance of choosing the optimum size of CHP plant in relation to actual energy demands. It stresses that CHP should not be sized on the current usage of heat and power if further energy saving measures are to be adopted after its installation, as such measures would change the whole viability of the CHP scheme. The section also deals with the technical aspects of CHP options, and recommends a technique for undertaking an initial site assessment. Check lists are provided to help determine the suitability of a potential site for CHP.

  Hospitals are good candidates for CHP plant as most of them operate continuously, with a well-defined electricity and heat base load, but each site must be individually appraised. Before the installation of CHP, a detailed review of current site energy performance should be undertaken to ensure that all cost-effective energy saving measures have been adopted, and that future changes in energy loads taken into account; prior to the installation of CHP.

- **Section 5 - Interfacing CHP into the Hospital**

  This section examines the control implications of CHP and its integration with existing electrical, space-heating and domestic hot water systems, together with reference to relevant technical regulations.

  The effects of electricity generation into the local hospital system is also considered. Short-circuit fault currents may be incteased beyond acceptable levels and the electrical protection discrimination may need to be revised or replacement switchgear installed. Guidance is given on deciding how and where electrical output from the CHP unit(s) can be connected into the existing system. Standby arrangements are discussed with particular reference to the paramount importance of the integrity of the emergency electrical supply system.

- **Section 6 - Economics and Financing**

  This section presents methods of financial and economic evaluation, together with the various financing options. Typically, CHP plant will cost at least £500 per kilowatt of installed electrical capacity with the cost being recovered in 3 - 5 years. A wide range of options is available for financing CHP in the Health Service, with some equipment suppliers providing guaranteed savings with little risk to the user and several CHP manufacturers also offering maintenance-inclusive packages.

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3 For the purpose of this guide, small-scale CHP refers to a packaged unit generating less than 500 kWe, while large-scale CHP covers schemes in the range 500 kWe to over 10 MWe. As the principal market in the health service will be for small-scale generation, most text refers to small-scale units. For the most part, the principles of operation are identical for small and large-scale CHP; where there is a difference, reference will also be made to large-scale schemes.

Evaluation techniques (simple payback and Benefit Cost Ratio (BCR)) are examined, with worked examples being provided, to enable comparison of CHP options and to ensure that the best one is selected.

- **Section 7 - Case Studies**

  This section provides case studies which illustrate the implementation of successful CHP schemes at a wide range of Health Service sites.

- **Appendix 1 - Detailed Design and Plant Specification**

  This appendix specifies a more detailed design exercise, to be carried out when the main operational parameters have been determined in order to optimise the possible savings and to guarantee that CHP is satisfactorily integrated into existing hospital services.

- **Appendix 2 - The Conversion of Existing Standby Generators to CHP Operation**

  This appendix discusses the potential benefits and the possible problems which could be encountered during conversion of standby generators to CHP operation.

- **Appendix 3 - Relevant Acts of Parliament, Statutory Regulations and Guidance Notes**

  This appendix lists the requirements for CHP installations, detailing the differences for installations in England, Scotland and Wales and those in Northern Ireland.

  It is a statutory requirement that Regional Electricity Companies (RECs) are consulted if there is any possibility of electrical generating plant being connected in parallel with their system. In practice, it is fundamental that the local REC's technical department is consulted at a very early stage to enable them to define their requirements at the outset for incorporation within any equipment specification. The regulations under the terms of the Electricity Acts applying to England and Wales, and those applying to Scotland and Northern Ireland, are discussed.

- **Appendix 4 - References and Further Information**

  This appendix lists sources of further information and where they are available from, to enable hospitals contemplating CHP installations to find sufficient background information. Addresses of organisations who can offer advice on the selection of specialist consultants are also given, which will be particularly useful to hospitals with insufficient in-house resources to carry out an investigation into the viability of CHP.

2. CHP IN THE HEALTH CARE ENVIRONMENT

The generation of electricity at a conventional power station often results in about 70% of the available primary energy being 'lost' in cooling towers, conversion and transmission. The delivered efficiency of centrally generated electricity is therefore only around 30%. CHP aims to reduce this waste by recovering as much of the heat as possible, resulting in typical efficiencies of over 80%. To achieve this aim, the electrical generator and its associated prime mover (e.g. engine) must be located close to a potential heat sink, that is a building or process with a sufficiently high thermal energy demand to utilise the waste heat recovered from the CHP system.

CHP units make use of a relatively low cost fuel, typically natural gas or oil, to generate both heat and electricity. They reduce the need to use conventional boilers, and to purchase electricity at a high cost per unit of energy from a public supply company. A CHP unit is generally less efficient than a boiler as a heat generator, but this disadvantage is offset by the savings in electrical energy supply and occasionally by reducing electricity Maximum Demand (MD) charges. A further important issue is that CHP results in national reductions of emissions to the environment, and the overall contribution to global warming is reduced.

Hospitals are potential candidates for CHP as most operate continuously and have a significant base load minimum demand for electricity and hot water/steam. However, each site must be assessed individually.

CHP will not reduce the energy requirements of a site, but a successful installation will reduce the costs of providing that energy. It should not be installed until other no cost and low cost energy saving methods have been employed. The viability of CHP depends upon choosing the optimum size unit in relation to the real electrical and heat demands. It is important not to size a CHP installation based on the current use of heat and power if further energy saving measures are to be adopted after its installation. In general, the return on capital invested in a CHP project is four times as sensitive to changes in the price of electricity as it is to the cost of primary fuels.

The use of CHP in hospitals is not new. A survey undertaken early in 1991 identified that over 92 small-scale systems of less than 500 kWe (installed electrical capacity) were already operational at 74 hospital sites throughout the UK, representing a combined electrical output of 8.25 MWe. In addition, there were a growing number of large-scale CHP schemes, with at least 15 MWe of combined electrical output already operational, and further schemes were being designed and installed. A further 25 MWe of electrical capacity (over six separate sites) was in the final stages of detailed design and specification.

Modern small-scale CHP units[4] should not be confused with the 'first generation' units which were introduced during the late 1970s and early 1980s. These early units were often based on the use of modified automotive engines, and their reliability was poor with maintenance costs often considerably higher than anticipated.

A 'second generation' of small-scale CHP units has now been developed. Major advances have been made in engine technology, and most systems now incorporate an 'on-board' or remote computerised fault diagnostic and monitoring system, which has dramatically improved system reliability, maintenance scheduling and machine availability.

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4 Further information on small-scale CHP is available in Good Practice Guide 3 'Introduction to Small-Scale Combined Heat and Power', and New Practice Final Profile and Report No. 41 'Remote Monitoring of Second Generation Small-Scale CHP Units'. Copies of these publications are available from ETSU's Energy Efficiency Enquiries Bureau (Tel. No: 0235 436747).

In summary, CHP has a valuable cost saving role to play at many hospital'sites. There are many options regarding equipment type and size, and there are few hospitals which are totally unsuitable for CHP in some form. Lack of skilled manpower or finance need not be constraints, with most manufacturers now offering fully financed and operated 'black box' systems, and many offering guaranteed savings. The intrinsic reliability of modern CHP plant, together with the willingness of many manufacturers to accept the risks and penalties associated with poor performance, provides an opportunity for many hospitals to gain the benefits of CHP without undue risk.

It is strongly recommended that each hospital undertakes a CHP review. Using the guidance provided in this document it will be possible to determine if CHP is feasible in principle, with manufacturers and/or consultants being used to optimise the final plant specification if feasibility is proved.

2.1 CHP Strategy

In the majority of cases, CHP will be considered on sites already fitted with adequate standby provision. Under these circumstances it is important to consider the economics of CHP on its own merits, in isolation from questions of standby. If the introduction of CHP looks attractive in principle, then the options associated with integrating the CHP system with the existing standby system should be examined, to improve the level of standby provision and/or to enhance the overall economic case. If the existing standby is inadequate or a new development is being assessed, then incorporation of CHP into the standby system is worth considering. In addition, the separate evaluation of CHP from standby permits natural gas to be used without contradicting the requirements for stored fuels.

Security of electrical supply is of the utmost importance at many hospital sites and it is essential that the provision of standby power is not compromised in any way by the CHP system. For this reason most small-scale CHP systems are installed in isolation from the standby system and will automatically shut down in the event of mains failure. Careful integration of the CHP electrical output to augment the standby system should be pursued and implemented only if the security of supply and/or the financial case for CHP is enhanced by so doing. It is of considerable importance that the mains supply from the Regional Electricity Company (REC) is **not** considered as a standby supply to CHP.

The introduction of CHP onto a hospital site should not diminish the security of the supply currently available. Existing generators should not be converted to CHP without the provision of additional electrical standby capacity to cover all essential loads and any additional loads deemed necessary by the hospital. The additional standby capacity is required for the maintenance downtime of the CHP plant.

If correctly designed and specified the installation of a CHP system can be a cost-effective investment. However, the payback time may be considerably longer than that of a wide range of more straightforward energy saving technologies, such as building envelope insulation, heat recovery and time/temperature controls.

Before considering a CHP system, every effort must be made to reduce the overall energy requirements. CHP should only be considered if the hospital has already made all practical efforts to implement more cost effective investments. The importance of this cannot be over-stressed, since the incorporation of simple energy saving technologies can have a profound effect on the overall site energy requirement. Simple energy saving.measures may dramatically change the heat:power ratio, which could subsequently affect the optimum size and type of CHP system required.

The strategy for the adoption of CHP in hospitals should complete the following steps:

Step 1 Review in detail the existing energy saving measures to ensure that all other more cost-effective measures have been identified and implemented prior to the specification of the CHP unit. If the site heating system is decentralised then small-scale CHP units each serving individual buildings may be appropriate. However, if the site is served by a central boiler house, a single, more significant CHP scheme should be considered.

Step 2 Review the adequacy of existing standby arrangements and consider whether conversion to CHP is practical and/or cost effective. In most cases conversion will **not** be appropriate. Size matching needs to be a consideration if existing standby generation arrangements are being reviewed.

Step 3 Undertake a preliminary review of historic energy consumption to determine the thermal and electrical load profiles and the base loads. This should be carried out initially on the basis of annual and monthly data, including typical daily profiles.

Step 4 If the CHP system is to operate well below the thermal and electrical base load requirements, it can be sized and quotations for the installation can be obtained, with simple payback and Benefit Cost Ratio (BCR) (see Section 6.1) being calculated. However, if the unit is to be sized at or above the base load, to partially follow fluctuating demands, or to export power and/or dump heat, then a detailed review of the thermal and electrical loads must be undertaken. The review will require the production of load-duration curves for the whole site, together with a detailed technical and economic evaluation, to optimise the plant size and type, the number of units and the mode of operation. It is at this step that Capital Charges should be taken into account.

Step 5 Consider if any cost-effective and viable options are available for integrating the CHP system with the existing, or planned, standby power provision to enhance the level of standby provided for non-essential loads. In most cases the CHP system will operate in isolation from the standby installation and will shut down automatically in the event of mains failure.

Step 6 Obtain budgetary quotations and examine financing options. Undertake a detailed financial evaluation, with BCRs being used to predict the viability of the short listed options over the plant life and to formulate a bid for finance.

Step 7 Undertake the preparation of brief and design, evaluate tenders, undertake procurement, installation and operation of the system.

Step 8 Monitor and evaluate the on-going system performance.

2.2 Hospital Engineering Services

The building services associated with hospitals are often highly complex. In addition to the usual space-heating and electrical services, many hospitals also require other services such as the provision of steam (for space-heating and/or sterilisation), medical gases, air-conditioning, clinical waste incineration and standby power provision. It is important that no aspect of hospital building services is considered in isolation, since considerable interdependence between the services exists. For this reason, any proposal to introduce CHP should not be considered without due regard to other major issues such as security of supply, safety, maintenance, noise and so on.

2.3 Environmental Issues

One of the greatest threats to the health of the nation is the environmental deterioration resulting from pollution in all its forms. Hospitals have a duty to promote health gain, which involves in the broader sense the conservation and use of sustainable natural resources, and to minimise the damage to the environment resulting from their own activities, encouraging others to follow their example. Any organisation whose primary objective is health care should seek to minimise emissions to the environment which are hazardous to health. Environmental factors should be taken into account when assessing the economic case for CHP.

In the 'European Charter on Environment and Health', the World Health Organisation states:

> ***'Every public and private body should assess its activities and carry them out in such a way as to protect people's health from harmful effects related to the physical, chemical, biological, microbiological and social environments. Each of these bodies should be accountable for its actions.'***

These views are repeated in the Government's 1990 White Paper on the Environment, entitled 'This Common Inheritance'.

Much of the energy used today is derived from non-renewable resources, and its generation inflicts environmental damage both directly and indirectly. The burning of fossil fuels is the single largest source of pollution and is responsible for the greatest proportion of carbon dioxide (CO_2) produced each year, the principal greenhouse gas which contributes to global warming.

CHP installations generate electricity and make use of most of the heat that is wasted in conventional power generation. In addition, nearly all CHP systems currently installed in hospital buildings are fired by natural gas. Consequently, the use of CHP results in:

- reduced production of CO_2;
- reduced pollution (for example, nitrogen oxides (NO_x) and sulphur oxides (SO_x) which are the principal sources of acid rain, and particulates);
- reduced use of finite natural resources.

3. THE APPLICATION OF CHP

3.1 What is CHP?

The main components of a small-scale CHP unit are shown in Fig 1. These include:

- an engine, often referred to as a prime mover, which drives the generator;
- a generator, which produces the electricity;
- a heat recovery system, to recover waste heat from the engine jacket and exhaust gases;
- a control system, to ensure safe and efficient operation (often including a fault monitoring and diagnostic system with a modem for remote alarm signalling);
- an exhaust system, to carry away the products of combustion;
- an acoustic enclosure, to prevent excess noise and to give weather and fire protection.

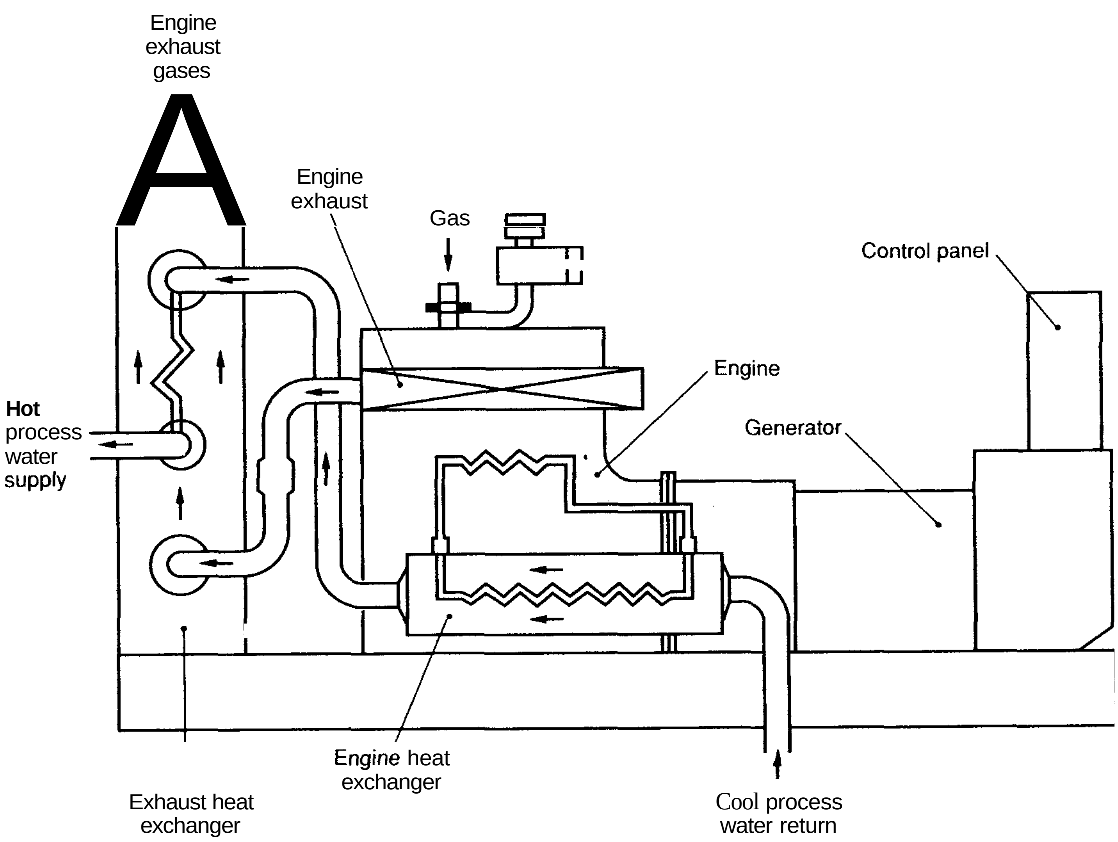


Fig 1 Small-scale packaged CHP unit components

Small-scale CHP units (i.e. those with less than 500 kWe output) are generally described as 'packaged' units, with all the main components being factory-assembled on a skid-mounted base unit. This assembly enables units to be run and fully checked for safety and performance before being installed on site. Within the health service, many opportunities exist for the cost-effective installation of these packaged units. Systems based on the use of gas turbines, large diesel engines and steam turbines are also finding applications on larger hospital sites.

Optimum performance for a small-scale CHP unit is obtained where a base load thermal to electrical power consumption (heat:power) ratio of between 2:1 and 3:1 exists, the primary aim being to utilise all the thermal and electrical output of the system.

The requirements for each CHP installation are unique, since steam and/or hot water conditions, power and heat demand are different for each hospital. A range of CHP types, sizes and options is available enabling a satisfactory solution to be produced for each particular installation. Fig 2 provides an indication of the range of heat:power ratios available from different CHP configurations.

To be cost-effective a CHP unit usually has to run for at least 4,500 hours each year at full load. Different criteria apply for large or complex schemes, and a detailed assessment should always be undertaken to determine the viability of any proposal.

The smallest CHP unit currently available has an electrical output of about 20 kWe, with a thermal output of 38 kW and a fuel input of 80 kW.

3.2 Types of CHP Unit

CHP units are generally classified by type of prime mover (i.e. drive system), generator and fuel used. The following sections examine the main types of CHP unit and the factors affecting their use and application within the health service.

3.2.1 *Prime Movers*

Drive systems for CHP units include:

(i) reciprocating engines;

(ii) gas turbines;

(iii) steam turbines;

(iv) combined cycle.

A summary of the various attributes of each type of system is given in Table 1 and is shown in diagrammatic form in Fig 2.

(i) Reciprocating Engines

Reciprocating engines have been widely used for CHP applications for many years. These engines may either be spark ignition or compression ignition engines, depending on the method of combustion.

Reciprocating engines used for CHP generally fall into the following categories:

- ***Automotive: Petrol derivatives***

  These spark ignition engines are often automotive derivatives (i.e. modified and derated car engines) with power outputs in the range 15 - 30 kWe. Engine life is generally in the range 10,000- 30,000 hours, compared with 2,000 - 6,000 for a car engine. The extended engine life is achieved by running at a constant slower speed (typically 1,500rpm) with steady load conditions. Converted petrol engines are small and light and have a relatively high power output.

- ***Automotive : Diesel derivatives***

  These spark ignition engines are generally used for electrical loads from 35 kWe to 200 kWe. The engines are normally substantially modified (pistons, heads, valve gear, ignition and fuel systems, etc.) to enable them to operate on natural gas. These modifications extend engine life considerably, generally to around 30,000 hours, and also increase the interval between servicing.

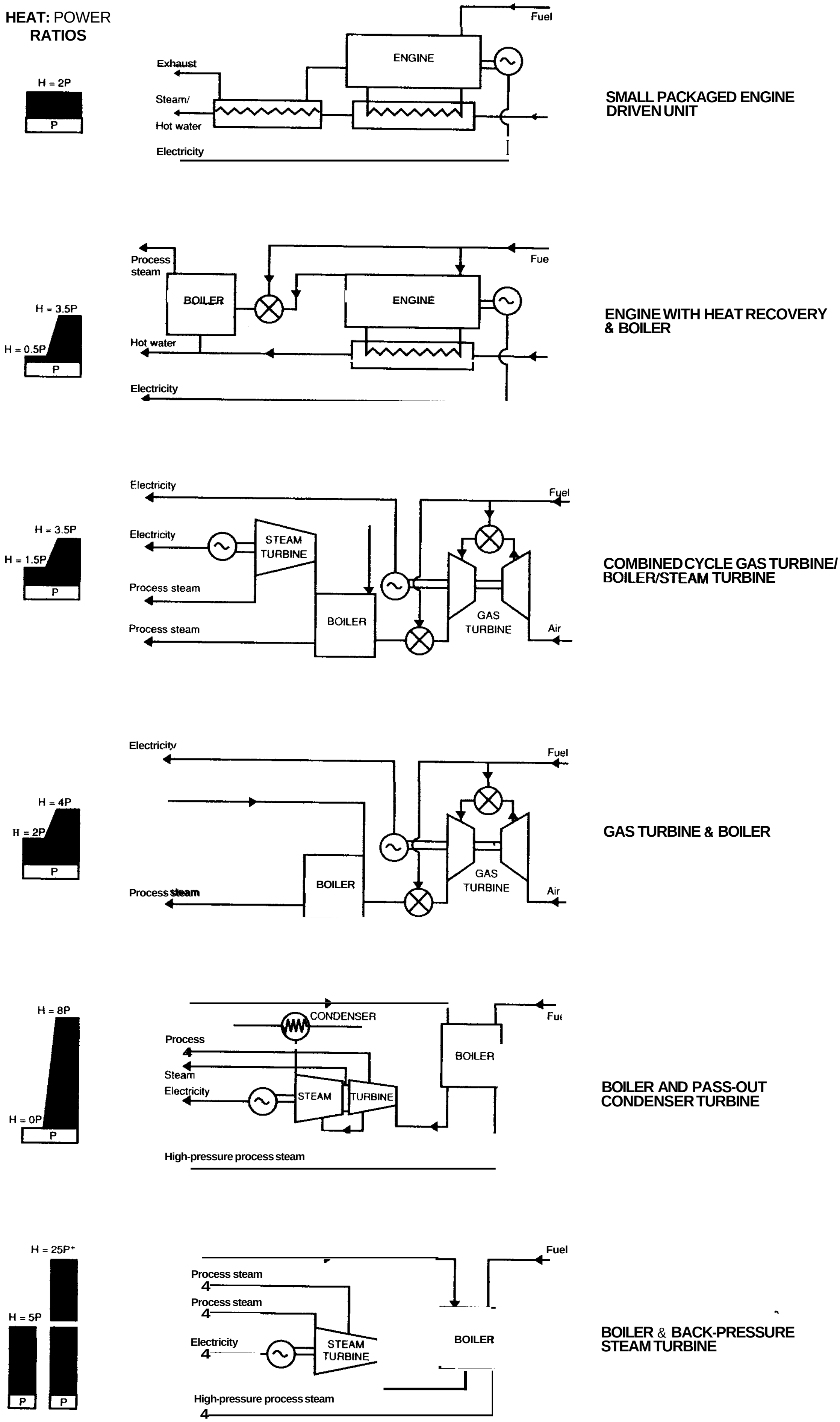


Fig 2 Typical heat:power ratios for different CHP configurations

Table 1 Typical characteristics of various prime movers
NB Efficiencies are based on gross calorific value

Prime Mover	Spark ignition	Compression	Open cycle	Combined cycle gas turbines	Back pressure steam turbines	Pass out steam turbines
				Gas Biogas Gas oil	Any fuel	Any fuel
Typical capacity range	30 kWe to 2 MWe	100kWe to 20 MWe	1MWe and upwards	3 MWe and upwards	500 kWe and upwards	1 MWe and upwards
Heat:Power ratio	1:1 to 2:1	0.5:1 to 1.5:1 (3:1 with boost firing)	1.5:1 to 2.5:1 (5:1 with supplementary firing)	1:1 (3:1 with supplementary firing)	3:1 to 10:1 and upwards	3:1 to 8:1 and upwards
Heat output quality	LPHW and steam (rare)	Steam and LPHW	High grade steam	Medium grade steam	Medium grade steam	Steam at 2 pressures
Electrical generating efficiency %	25 - 33	35 - 42	25 - 40	35 - 50	7 - 20	10 - 20
Overall efficiency %	70 - 78	65 - 75 (75 - 82 with boost firing)	65 - 80 (75 - 82 with supplementary firing)	73 - 80 (80 - 85 with supplementary firing)	75 - 84	75 - 84
Capital cost £/kWe	550 - 850	500-800	500-1500	500-700	600-2000	600-2000
Operation & maintenance cost p/kWh	0.5 - 0.8	0.4 - 0.8	0.2 - 0.7	0.2 - 0.7	0.1	0.1

- ***Stationary engines***

  These compression ignition engines are heavy and rugged and were originally designed for applications in industry or ships. They are designed for electrical loads of up to 3 MWe and require little maintenance. Although maintenance costs are low and the life expectancy is high, the investment needed for these engines is high, and they are normally only specified for applications requiring continuous operation at high load.

- ***Dual fuel stationary engines***

  These are basically compression ignition diesel engines running on about 90% natural gas, with gas oil injection to ignite the fuel. They have the advantage of being. able to run on gas oil or gas, which makes it possible to use an interruptible gas supply. Their primary disadvantage is cost, since the investment cost is substantially higher than for comparable single fuel engines. Two separate fuel supply systems are required which also adds to the cost and complexity of controls and instrumentation. This type of engine is available for loads from 750 kWe to 6 MWe.

The above diesel engines for loads from *30* kWe to 6 MWe can operate on gas oil, and in the past have been used for CHP applications; however, the economic case for their use is

currently not very attractive as a result of the comparatively high cost of diesel fuel, leading to the pre-eminent position of gas-fuelled spark ignition engines. All the engine types mentioned above can either be naturally aspirated or turbo-charged and intercooled. Current practice is to turbo-charge the larger engines, but there is a trend to turbo-charge even the small models, in order to obtain an increased power output and to enable lean burn operating modes to be achieved using existing designs.

(ii) Gas Turbines

Gas turbines are frequently used for CHP units above about 1 MWe, where heat recovery can produce high quality steam (i.e. high pressure). Gas turbines provide very high levels of availability and reliability (see Section 3.4), although plant operation and maintenance can require a higher level of skill and training than reciprocating engines; this maintenance is normally undertaken wholly or partially by the equipment supplier. Gas turbines burn natural gas, gas oil or heavy fuel oil (HFO).

Capital costs, in terms of £/kWe installed capacity, are generally higher than those for reciprocating engines in the smaller size range. Installed costs for gas turbine installations are influenced by the requirements for control and instrumentation, gas compression, supplementary firing, noise reduction and fire prevention equipment. Costs associated with these requirements can add substantially to the basic cost of a gas turbine, and need careful consideration at the design stage.

(iii) Steam Turbines

CHP units based on the use of a steam turbine prime mover have been used for many years. Steam turbine based units provide considerable flexibility in the choice of fuel for boiler firing. Typically these units produce a large amount of heat compared with the electrical output, resulting in a high cost installation in terms of £/kWe; however, the integration of a hospital incinerator with a steam turbine based CHP unit can in some cases be cost-effective. Power outputs are generally greater than 500 kWe.

(iv) Combined Cycle

Some large systems (power output generally greater than 3 MWe) utilise a combination of gas turbine and steam turbine, with the hot exhaust gases from the gas turbine being used to produce the steam for the steam turbine (i.e. in a combined cycle).

3.2.2 The Generator

The generators used in packaged CHP units have 3-phase alternating current (ac) outputs at 415 V, typically in the range 20 kWe upwards, and can be synchronous or asynchronous generators.

A synchronous generator can operate in isolation from other generating plant and the grid. The voltage and frequency when operating in this mode are determined solely by the control equipment of the unit. The speed of rotation of the rotor determines the frequency and remains virtually constant as the power demand of the load varies. This type of generator can continue to supply power during grid failure and so can act as a standby generator. In addition, since this type of unit starts from batteries, it does not affect the grid voltage on start-up.

A mains-excited asynchronous generator can only operate in parallel with other generators (usually the grid), with adequate reactive power to supply magnetic excitation. The grid determines the voltage and frequency of the unit, and the unit itself will therefore cease to operate if it is disconnected from the mains or if the mains fail. The output frequency is automatically matched to that of the mains, and therefore connection and interface to the grid is simple. CHP units using asynchronous generation are also inherently safe from the

Electricity Supply Industry's point of view, in as much as the generator will not provide power if the grid fails and so there is no risk of inadvertent supply of electricity when the grid is being maintained. However, because these generators need mains excitation, they cannot be operated as standby units. They are also subject to regulations limiting the voltage fluctuations imposed on the grid on start-up, although experience indicates that this is rarely a problem.

Synchronous generators with outputs below 100 kWe are usually more expensive than asynchronous units, because of the additional control, starting and interfacing equipment required. In general, above 100 kWe output the cost advantages of asynchronous over synchronous types disappear. The current trend is to use synchronous generators even on low power output CHP units.

3.3 CHP Heat:Power Ratio

The ratio of heat to power required by a site may vary during different times of the day and seasons of the year. **A** shortfall in electrical output from the CHP unit can be made up by importing power from the grid, with any shortfall in thermal output being achieved by firing boilers.

If a requirement exists for chilling or air-conditioning, consideration should be given to the possible benefits of using the thermal output of the CHP unit as the heat source for an absorption refrigeration system. This technique can ensure that the thermal output of the CHP unit is fully utilised throughout the year.

Many large CHP units utilise the waste heat from the turbine or engine exhaust together with 'supplementary' or 'boost' firing, in order to modify the heat:power ratio and provide a satisfactory energy balance. Supplementary firing enables the energy content of the exhaust gases, which are rich in oxygen, to be fully utilised by mixing them with a suitable fuel (gas or oil) and burning the product in the duct before passing to a waste heat boiler. This technique is extremely energy efficient (around 95%) as generally no extra combustion air is required. It can also help to reduce the level of pollutant emissions (carbon monoxide (CO), NO_x, etc.), by ensuring complete combustion of the exhaust gases prior to discharge to the atmosphere.

3.4 Availability and Reliability

The availability and reliability of the prime mover of a CHP unit are extremely important. In order to be profitable, CHP must operate over extended periods, in many cases almost continuously. However, maintenance necessitates a scheduled shutdown at least once a year, and there may be additional unscheduled stoppages.

The reliability of a prime mover is a measure of its susceptibility to unscheduled shutdown; availability takes into account all outages. The distinction between the two is often blurred and manufacturers' specifications and guarantees should be carefully scrutinised to ensure a true understanding. The time period used for calculations is typically a year of 8,760 hours (365 days at 24 hours per day). The formulae below illustrate one method of making the calculations:

$$\%\ Reliability = \frac{T - (S + U)}{(T - S)} \times 100$$

$$\%Availability = \frac{T - (S + U)}{T} \times 100$$

where: **S** = scheduled maintenance shutdown, **U** = unscheduled shutdown and T = time period when plant is required to be in service or available for service, all expressed in hours per year.

3.5 Standby Power and CHP

Where the integration of **CHP** and standby is being considered for a new building or major refurbishment, a thorough risk analysis should be undertaken and specialist advice sought bearing in mind current **NHS** guidance.

In cases where **CHP** alone is to provide the standby requirement, sufficient plant capacity and number of units must be provided to ensure security of supply and to cover maintenance downtime. To comply with **NHS** guidance, the plant should be capable of running on a stored fuel, such as oil. **CHP** plant needs to satisfy electrical connection requirements (see Appendix *3)* and this is particularly important where **CHP** is to be used in a dual role as standby plant.

Many problems have been experienced with the conversion of existing standby generators to **CHP,** resulting in a number of unsuccessful schemes. Appendix 2 deals with this aspect in greater detail. The main problems associated with the conversion of existing standby generators to **CHP** operation include the following:

- considerably lower than expected heat recovery from engines;
- conversions taking longer than expected and over-running cost estimates;
- lower annual running hours than anticipated on some sites, due to poor reliability;
- higher than expected maintenance costs;
- additional risks associated with standby power provision;
- difficulty in predicting the long term financial viability of the conversion if based on the use of a diesel generator, as a result of the volatility of oil prices.

4. TECHNICAL APPRAISAL

It is recommended that the appraisal of CHP should be undertaken in two stages.

Stage I Initial appraisal to determine if it is worth committing the resources necessary to undertake a detailed technical appraisal.

Stage 2 If stage 1 determines that CHP is viable in principle, a detailed technical appraisal should be undertaken. This second appraisal will involve analysing a significant amount of accurate load and site data, to enable an efficient and cost-effective CHP unit to be specified. It will also determine if the overall plant performance can be enhanced by plant optimisation, export of electricity, heat dumping and integration of CHP with the existing standby plant (refer to Section 5).

4.1 Initial Site Assessment

To be successful, a CHP scheme must be carefully designed to suit individual site parameters and conditions. For maximum effectiveness, the heat and electricity generated should be fully utilised on site. To achieve this, the heat and electricity consumption profiles must match those generated in the correct proportion and the CHP unit must be sized for the limiting factors.

The following section is intended to assist site managers undertaking an initial assessment to determine whether installing CHP is likely to be cost-effective. Detailed performance analysis and financial appraisal of CHP options, capital costs and savings can involve a substantial work load and should only be carried out if the initial assessment produces encouraging results.

Figs **3** and 4 together with Table 2 will assist in identifying sites which would not be suitable for CHP because of insufficient heat loads, or heat and electrical loads which are out of balance.

This initial assessment process may be applied to whole sites or individual premises where there is:

- a fossil fuel fired boiler house providing heating or domestic hot water;
- a calorifier plant near to local electrical distribution;
- a hydrotherapy or other heated swimming pool.

4.2 Detailed Site Assessment

If the initial assessment suggests that it is worth proceeding further, then more detailed investigatory work will have to be undertaken and resources allocated. Whether this work is undertaken in consultation with equipment suppliers or consultants will depend on financial and human resource availability.

The starting point for all detailed CHP feasibility studies is to gain an accurate assessment of the profile **of** electrical and thermal loads. The correct sizing of a CHP unit is essential to the viability of the installation. Furthermore, the correct sizing and choice of the prime mover is only possible if the heat and electricity demands are clearly defined.

4.2.1 *Electrical Load Assessment*

Electrical load profiles can be determined relatively easily using a portable load monitor, which can be hired from a number of organisations. The monitor will provide information

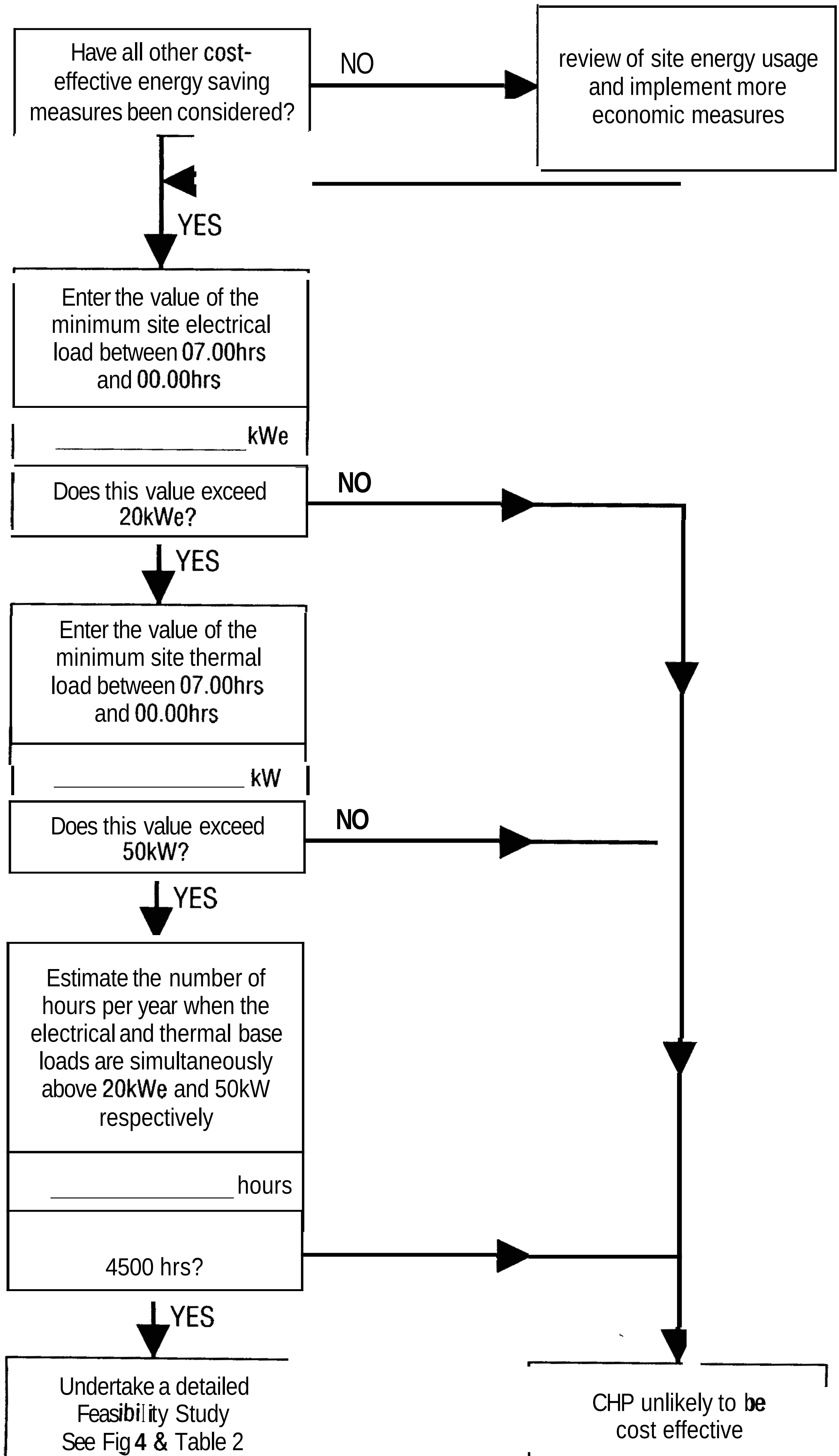


Fig 3 Strategy for CHP in hospitals - initial assessment

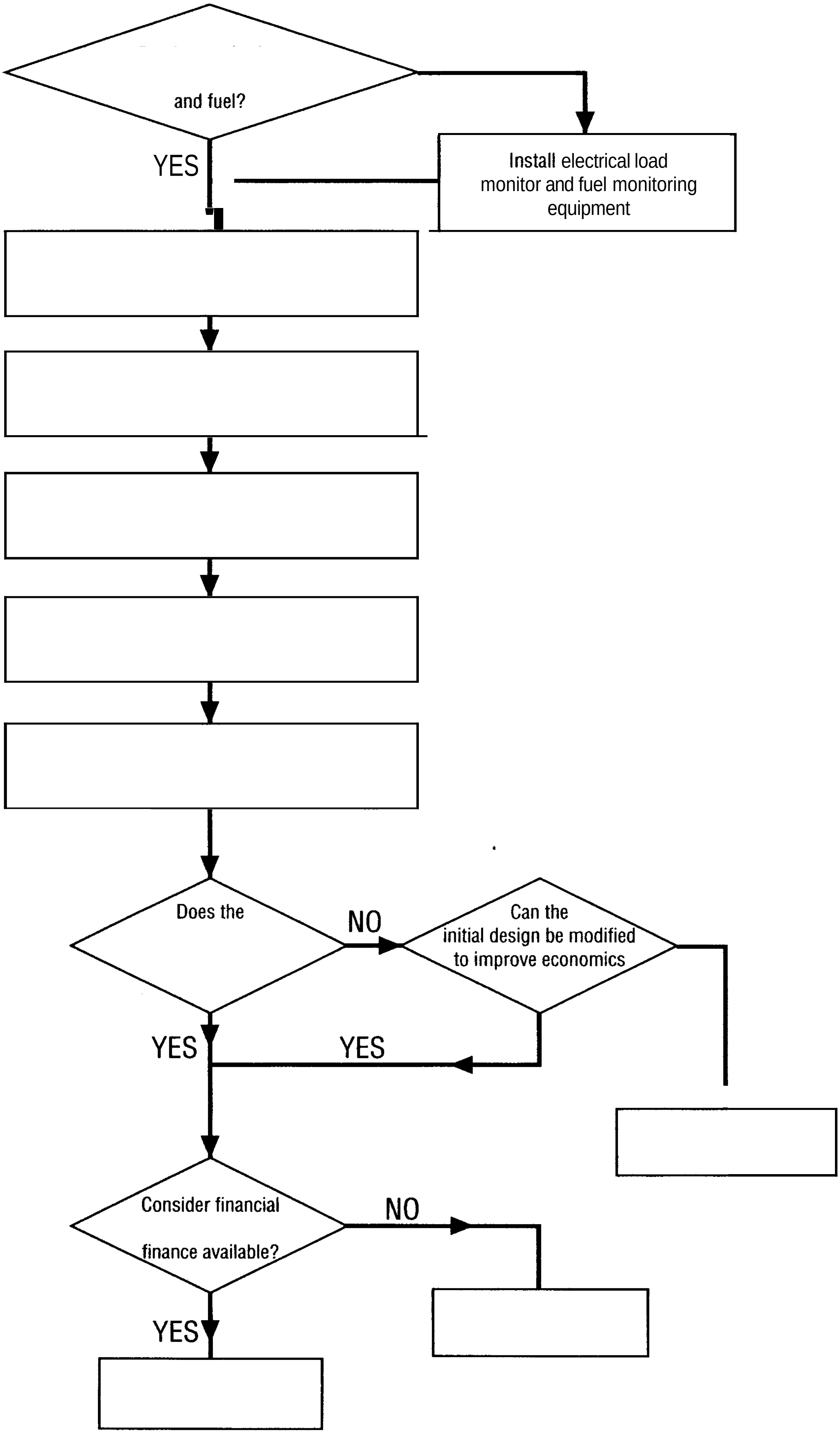
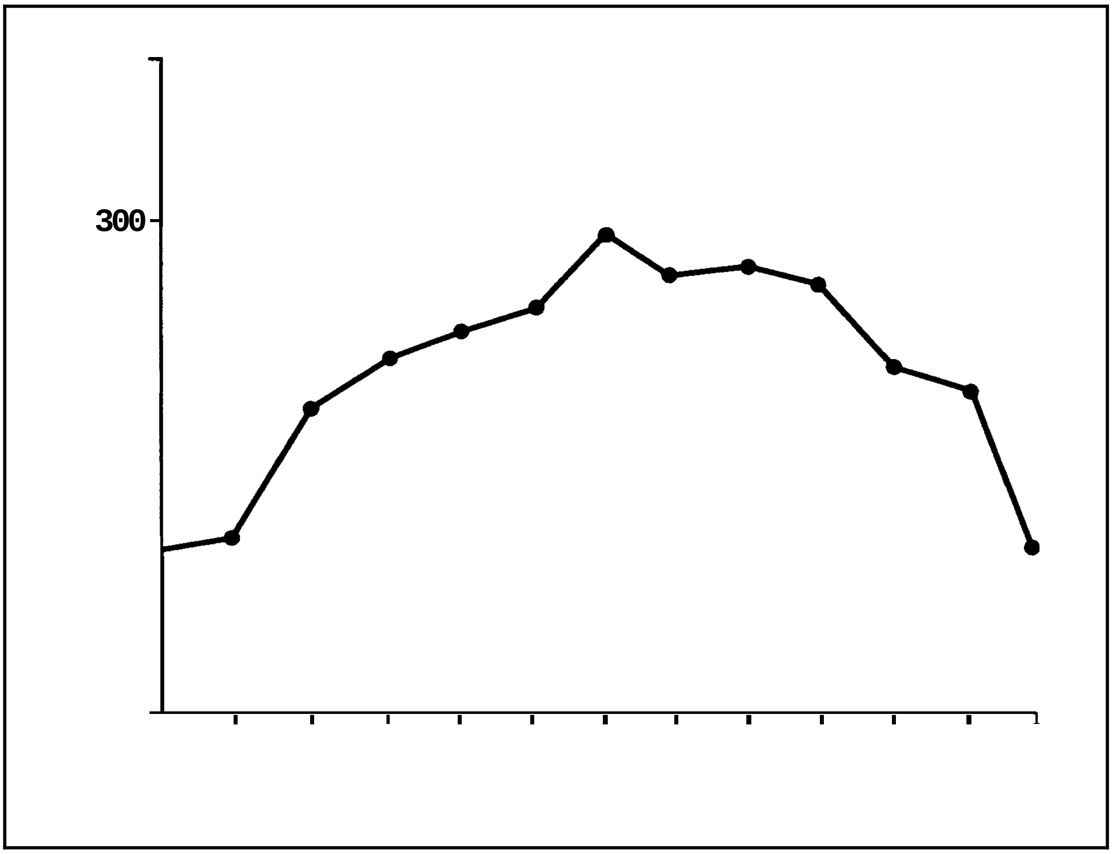

and fuel?
YES
Install electrical load monitor and fuel monitoring equipment
Does the
NO
Can the initial design be modified to improve economics
YES
YES
Consider financial
finance available?
NO
YES

Table 2 Essential requirements for the successful implementation of CHP in hospitals

	Yes/No
• Have all other energy saving measures been identified and either implemented or taken into consideration?	....
• Is there a simultaneous base load requirement for electricity and heat which exceeds 20 kWe and 50 kW respectively for more than 4,500 hours/year?	....
• Is there a suitable fuel supply (e.g. gas)?	....
• Is there suitable access and space for a CHP unit and is the location suitable with respect to patient care (e.g. noise, exhaust, etc.)?	
• Are the fuel and electricity consumption records available on a monthly basis?	....
• Are any site changes/developments planned and have the possible effects on the CHP size/economics been taken into account?	....
• Has the impact of CHP on the standby power provision been carefully considered with regard to security of supply, safety, etc?	....
• Have the fire safety aspects been considered?	....
• Have the requirements to upgrade any part of the existing heating, electrical distribution or control system as a result of the CHP installation been investigated?	....
• Is the proposed heat sink (i.e. hot water space-heating, swimming pool, etc.) near to the CHP unit location and electrical distribution system?	....
• If the CHP system is to be used for standby provision, will it satisfy the appropriate requirements (e.g. number and output of units, operation on a storable fuel, etc.)?	....
• Has the operation and maintenance cost been accurately assessed?	....
• Have all revenue costs been accurately assessed?	....
• Has a detailed financial evaluation and sensitivity analysis been undertaken?	....
• Has consideration been given to implications of capital (if any) charges?	....
• Are skilled and professional staff available (either in-house or on contract) to enable plant to be operated and maintained to provide maximum levels of reliability and efficiency?	....

CHP should not proceed unless the answer is 'YES' to all these questions.



Thermal loads are more difficult to measure with accuracy than electrical loads. However, it is very important that an accurate understanding of the thermal load is obtained. A number of existing **CHP** installations have not achieved the anticipated levels of saving as a direct consequence of the plant having been inaccurately specified, sometimes on the basis of the size of the previously installed boiler. This problem can be overcome if adequate site thermal demand measurements are made and a thermal-load profile produced. For the correct specification of **CHP,** the peak thermal demand of the site is of much less importance than the base load duration. **CHP** is generally only cost-effective if a sufficiently large heat requirement exists for the majority of the running hours. An example of a typical hot water load profile is given in Fig 6.

Thermal loads can be determined by taking hourly (or half hourly) readings of boiler gas meters, oil flow meters or steam meters over a typical 24 hour period. This procedure can be fairly tedious if undertaken manually, but is essential if the plant is to be correctly specified. Sometimes an existing Building Energy Management System (BEMS) can be used to determine the loads using either pulsed outputs from gas, heat or flow meters where fitted.

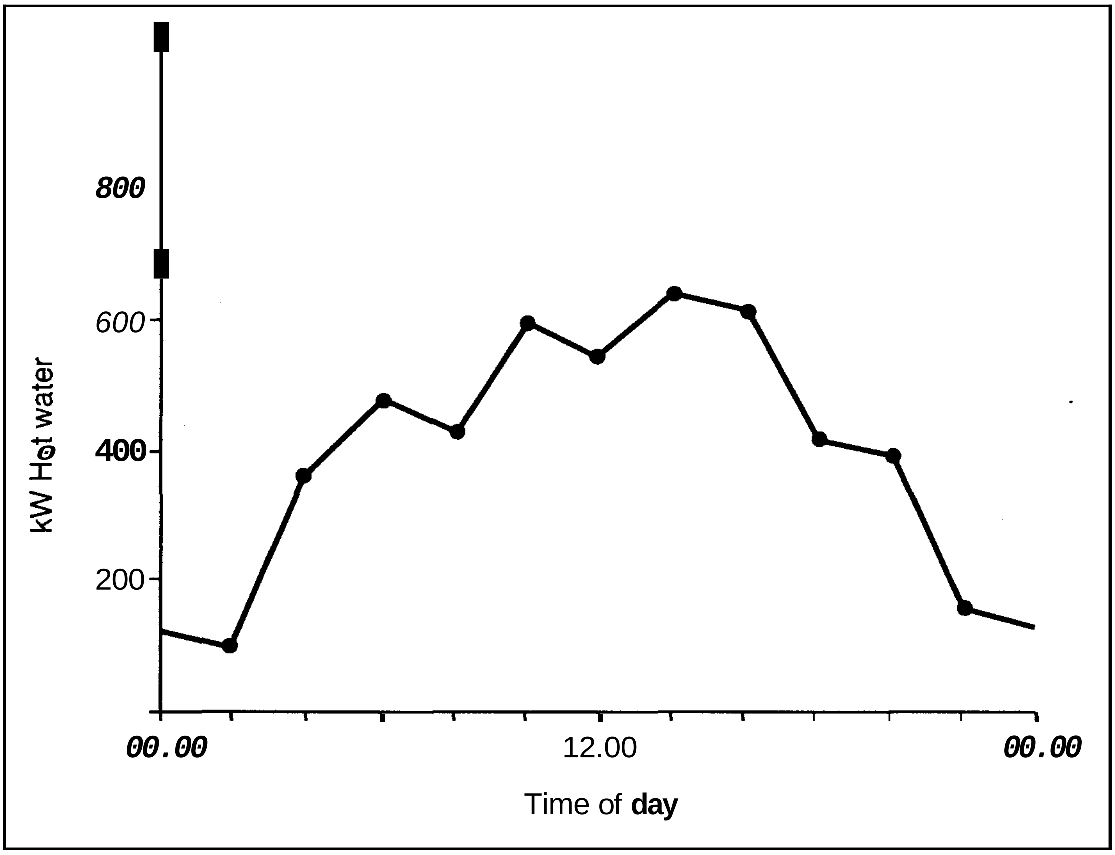


Fig 6 Typical hot water load profile

Some hospitals claim to have successfully used 'clip-on' ultrasonic flow meters to determine thermal loads; however, the results from these meters should be treated with caution and only used if they can be validated or cross-checked by another means. For boilers with simple on/off control, an alternative indirect method of estimating thermal loads is to install an 'hours run' meter on the boiler main fuel supply valve and, provided the boiler heat output and efficiency are known, the thermal load and duration can be deduced from hourly readings. As with electrical load monitoring, seasonal and weekday/ weekend differences in load must be determined.

In the majority of cases the CHP unit will be designed to satisfy the thermal base load only, for which it is generally adequate to undertake the thermal heat load monitoring in the summer when heating loads are isolated. If, however, the CHP unit is intended to contribute partially or wholly to the space-heating, air-conditioning or any other seasonal loads, additional monitoring should be undertaken as appropriate.

It is wrong to attempt to size the CHP unit on the basis of any of the following:

- output or number of existing boilers:
- number of hospital beds;
- hospital type.

It should also be noted that a number of the current practices used for sizing hot water plant will tend to result in a considerable overestimate of the actual site hot water requirements.

In addition to establishing an accurate assessment of thermal loads it is important to determine the temperature and/or steam pressure requirements for the different services.

This can normally be achieved by using a portable surface thermometer to measure flow and return temperatures.

CHP units are normally sized on the basis of the thermal base load, with the grid being used to supply the additional electrical load and boilers being used to supply any seasonal thermal variations. Generally, the longer the required running hours of a CHP unit, the more cost-effective the result. Systems that require the installation of heat storage facilities to achieve the required running time (i.e. more than 4,500 hours per year) may be considered as an option, but they are currently unlikely to be cost-effective.

4.2.3 *Load Duration Curves*

Producing thermal and electrical load duration curves for the site can be of considerable value if the CHP unit is to be operated with a thermal or electrical output greater than the respective base load.

Load duration curves indicate the cumulative hours demand that exists annually, and are constructed by plotting the number of hours per year that an installation operates at or below a certain output. Thermal load duration curves are shown in Figs 7 and 8, where the vertical axis represents the thermal demand and the horizontal axis represents the numbers of hours in the year. The illustrated curves indicate that an instantaneous peak thermal load of 750 kW was reached, and also that a thermal load of 530 kW occurred for 2,000 hours during the year. Load duration curves will enable a CHP unit to be accurately sized for economic operation and will also help to determine if more than one unit should be incorporated.

The production of load duration curves is a complex and time consuming process. It is recommended that if load duration curves are required, the assistance of a specialist consultant is obtained, who should have suitable computer software enabling the curves to be produced accurately.

4.2.4 *Sizing CHP for a New Hospital*

For a new hospital, no historical records of energy consumption will be available for sizing a CHP unit. An assessment can be made by examining the thermal and electrical requirements of a hospital having a similar design and function, and using the information to validate the theoretical estimates of kWh/m^2, GJ/m^3, and so on. Computer thermal modelling techniques are also useful for predicting the dynamic performance of a proposed building, and its likely space-heating load profiles.

4.2.5 *Initial System Sizing*

Generally CHP is likely to be viable provided the unit would run over 4,500 full load hours per year. For heating purposes it is not common practice to size a CHP installation to supply more than 50% of the maximum thermal demand. Normally, in small scale CHP applications this will provide as electrical output supplying between 10 and 30% of the site maximum electrical demand. The contribution to site heat and power requirements can be significantly higher in large applications, in particular deep plan hospitals. It is preferable to undersize slightly rather than oversize the CHP unit, as this will ensure longer running hours and more economic use of the capital resources. Considering these points and with the help of load duration curves, a CHP selection can be made. Figs 7 and 8 show the same thermal load curve with two possible CHP selections.

In Fig 7, a single CHP unit with a maximum thermal output of 290 kW is illustrated, which would work for around 4,600 hours at full load. Reciprocating engines will not run at less than 50% load at acceptable efficiency, and with gas turbines the limit is more likely to be 70%. With this limitation, the CHP unit in this example would operate for a further 1,859 hours at part load, and the remaining heat demand would be provided by firing boilers in the conventional manner.

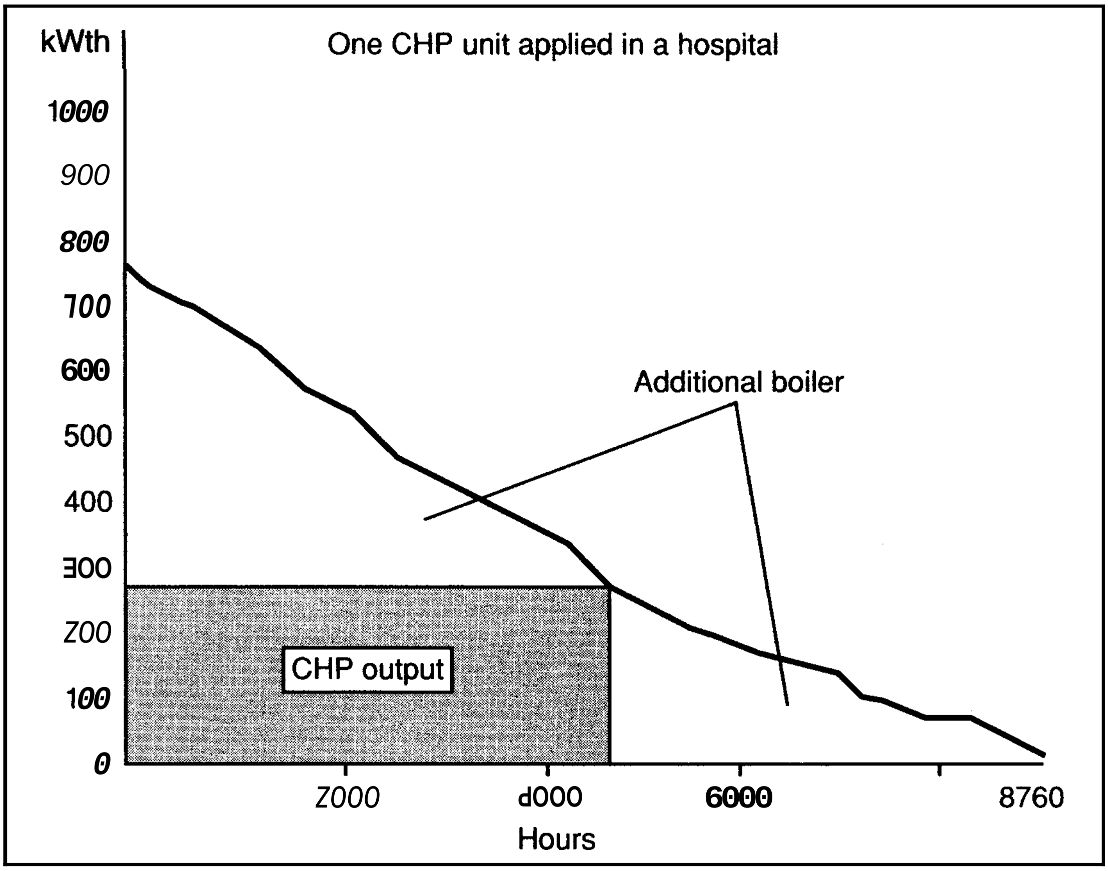


Fig 7 Thermal load curve illustrating possible CHP selection, using thermal output of one CHP unit

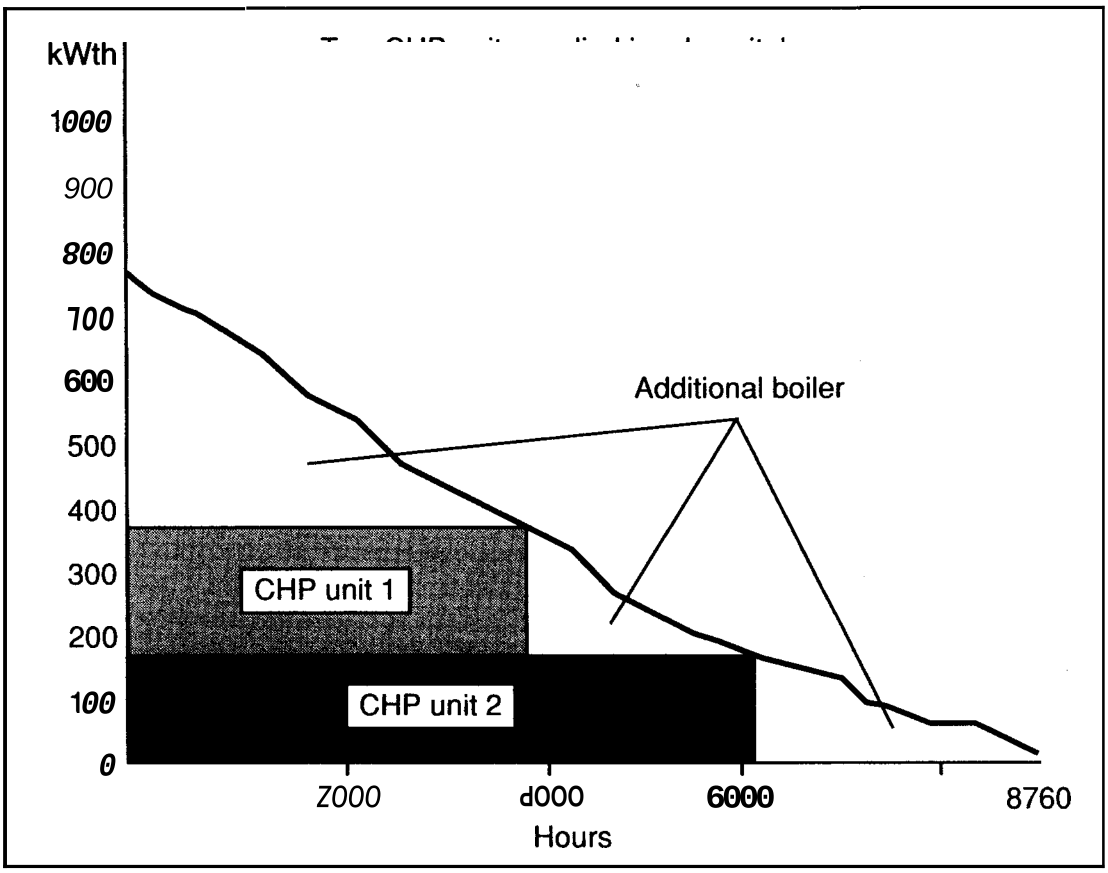


Fig 8 Thermal load curve showing possible CHP selection, using thermal output of two CHP units

In Fig 8, two CHP units are illustrated, each with a thermal output of 190 kW. One unit would run for 6,000 hours at full load and a further 2,000 at part load, and the second for around 5,000 hours at full load and 1,500 hours at part load.

Additional savings may be achievable by installing more than one CHP unit and exporting electricity (under certain tariff conditions only), or even ‘dumping’ heat and running the CHP unit to avoid incurring high Maximum Demand (MD) or Seasonal Time of Day (STOD) tariffs. These aspects should be the subject of a much more detailed design study and are discussed further in Appendix 1.

4.3 Relevant Technical and Statutory Regulations for CHP

The majority of regulations related to CHP are associated with electrical safety and protection. The involvement and assistance of a Regional Electricity Company (REC) at an early stage is essential to ensure that the CHP installation complies with all relevant electrical technical regulations. The relevant regulations, current at the time of publication, are summarised in Appendix 3. These summaries also take into account the differences between electricity regulations applied in England and Wales, and those applied in Scotland and Northern Ireland.

Technical documentation is constantly being revised and care should be taken to ensure that reference is made only to the latest edition of guidance.

5. INTERFACING CHP INTO THE HOSPITAL

CHP does not operate in isolation, and is always an integral part of a larger more complex installation. For efficient and reliable operation, the interface between the CHP installation and the existing heating, hot water and electrical network requires careful consideration. Also, provision must be made to supply, and possibly store, fuel for the CHP unit(s) and to vent the exhaust gases safely.

It should be stressed that the ultimate success of any CHP installation will depend upon being able to maximise the output of heat from the CHP unit into the hospital system. Although a suitably sized heat load may exist, a mismatch of flow rates and temperature could prohibit the full utilisation of the heat from the CHP unit and therefore undermine its economic viability. There are examples of this in hospitals where the basic appraisal criteria for viability were satisfied but the end result was unsatisfactory, because the heat sink was not compatible with the heat source. Interfacing CHP with existing systems requires careful engineering assessment and design.

5.1 Interfacing With The Heating System

A detailed review of the existing heating and domestic hot water (DHW) systems should be undertaken prior to the specification of the CHP installation. This will enable an understanding to be gained of their operation and also identify any services having poor performance or control. All controls, motorised, modulating and isolating valves should be carefully checked to ensure satisfactory operation. It is important to recognise that CHP delivers energy at a lower cost than when purchasing from a public supply company. It **does not** compensate for poor design or misuse of the existing services or their controls.

It is worth considering other possible uses for the heat available from CHP, including pre-heating boiler feedwater and running absorption refrigeration plant, if this will make it more viable.

To determine the optimum method of integrating CHP with other hospital heating and DHW systems, the following basic information is required:

- A schematic drawing of the system.
- Are the DHW and space heating systems supplied from common boiler plant?
- Are the DHW calorifiers fitted with diverting valves which will spill hot (flow temperature) water into the ‘cool’ return and so shut down the CHP unit?
- Is the system weather compensated, and if so, is it by variable temperature from the boiler or via a mixing valve, which would reduce the return volume to the boiler plant?
- Is operation of the boilers sequenced, and if so, is the temperature controlled on flow or return?
- Is the whole system, or a part of it, under the control of a Building Energy Management System (BEMS)?
- A Sankey diagram or heat balance for the site. An example of a typical Sankey diagram for a new, air-conditioned teaching hospital is given in Fig 9.
- A schedule of pumps and circuit water flows and pressure losses.
- A value for boiler efficiency (seasonal).

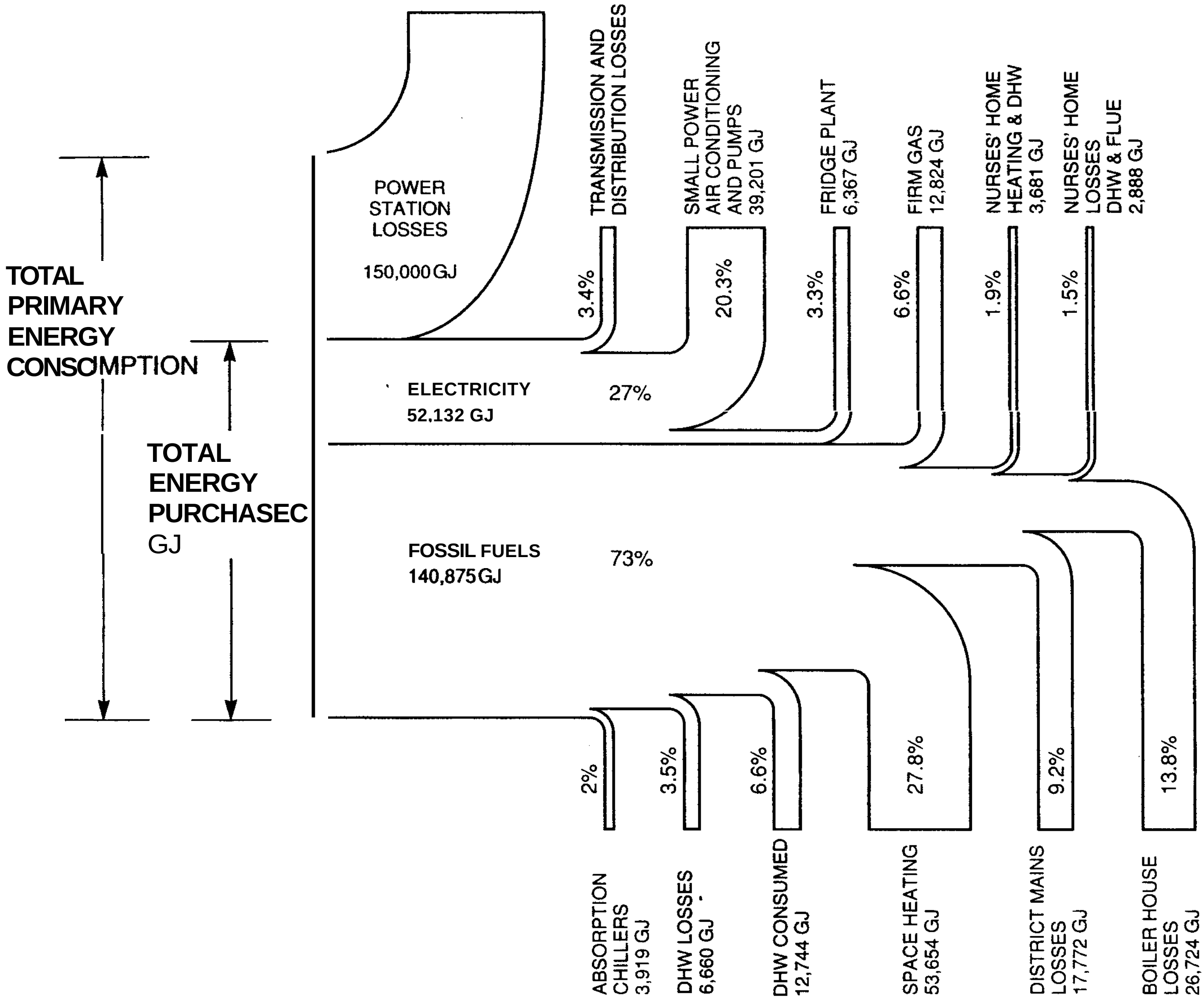


Fig 9 Sankey diagram of the total energy usage for a new, air-conditioned teaching hospital

5.2 Location of CHP installation

The selected location for the CHP installation must take account of the following:

- access to services - electrical, heating and fuel supplies;
- noise emissions;
- exhaust emissions;
- ventilation and air quality requirements;
- delivery, access and positioning of the system;
- maintenance requirements.

Generally small-scale packaged CHP units will be skid-mounted, with the smaller units able to be manoeuvred through a standard doorway. The larger units may need positioning by crane or may require alterations to the building in order to accommodate them. Some

manufacturers offer weatherproofed, fully silenced units intended to stand outside; however, before siting a unit either outdoors or in an area subject to frost, the supplier's advice should be sought. Unless engine pre-heating and oil circulation is provided, cold starts in winter may cause problems and, at least, will result in increased engine wear.

Large-scale CHP installations normally require a separate plant room/energy centre with all auxiliary plant, controls, protection equipment and so on, designed as a fully integrated system. If the CHP unit is being installed in an existing boiler house, it is likely that ventilation requirements will be met. Mechanical service plant rooms are often unventilated and may require extra ventilation if used.

A level surface should be provided for the CHP unit which is neither subject to flooding nor liable to suffer from the effects of vibration. If vibration is thought likely, consideration should be given to the use of anti-vibration mountings. Provision should be made for maintenance, including regular servicing such as heat exchanger dismantling and cleaning. Large-scale CHP installations require careful design to ensure that maintenance, including replacement of large components, such as gas turbines and heat exchangers, can be undertaken easily.

5.3 Heating System Connection

There are two main ways of connecting a packaged CHP unit into an existing heating system:

- 'in series' as a by-pass in a suitable return water feed to the boilers; this is generally the main return;

- 'in parallel' with the boilers.

Both these options are illustrated schematically in Fig 10. Which of the two methods is selected and precisely how CHP is connected will depend on the number and size of CHP unit(s) to be used and on the site appraisal, particularly with respect to water flow rates and return temperatures. In both cases, the CHP installation will operate as the 'lead' boiler. A dedicated CHP installation could supply heat to only the DHW systems or to the heating system, either at local level or in conjunction with the central boiler plant.

(i) Series Connection

The by-pass connection is frequently selected as the most suitable for introducing CHP into an existing installation, because it creates the minimum interference with existing flow and control arrangements. The water flow and return connections to the CHP unit are made via tappings, generally off the main return pipe from the radiators and/or hot water calorifier. Extra CHP units can be connected in a similar way.

In winter, the existing boilers will operate to provide the peak loads. In summer, it is probable that only one boiler will be operational and the flow path through it must be left open to allow the CHP unit to function correctly, which may lead to increased boiler standing losses. The CHP circuit has its own pump and flow rate, although it is likely to be far smaller than the flow through the main heating circuit. If motorised isolating valves are fitted to the boiler(s), a by-pass will be required which will allow at least the minimum CHP water flow to pass.

(ii) Parallel Connection

When setting up a totally new installation, especially where the CHP unit is likely to supply a significant proportion of the total heat load, it is better to install the unit in parallel with the boilers. This is particularly important if the boilers are to be controlled in such a way that the flow through them drops significantly under certain conditions. However, it is

important to ensure that the volumes of water flowing through the CHP unit and the boilers are correctly balanced.

An additional pump, specific to the CHP unit(s), will generally be required due to the high hydraulic resistance of CHP units compared with boilers.

Care is needed to ensure that the positions of the CHP tappings are not chosen **for** convenience alone, but also **for** their suitability, **i.e.** to ensure the correct volume of water is supplied at suitable temperatures.

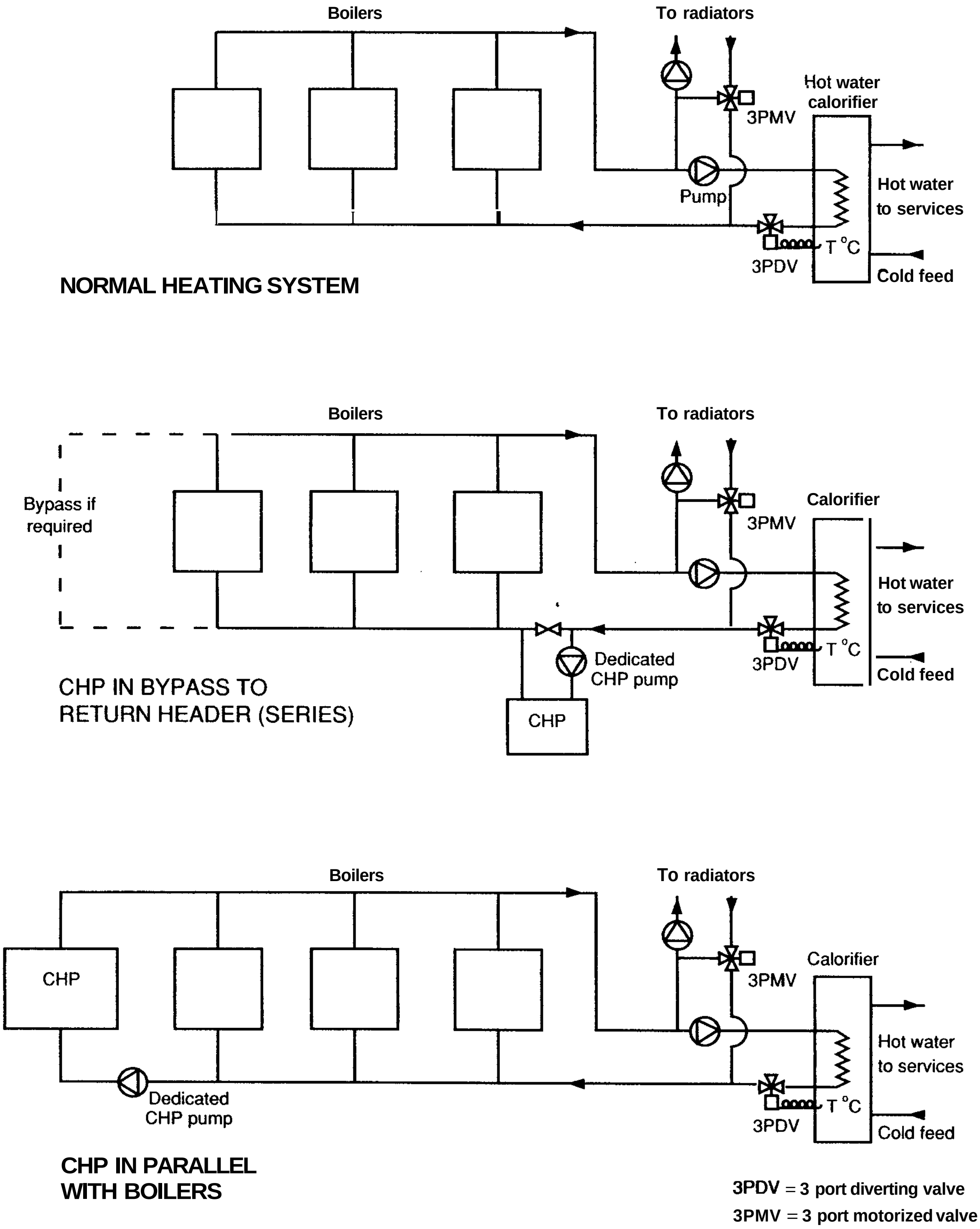


Fig 10 Typical CHP/heating system connections

(iii) Alternative Connection

The interconnection of a CHP unit is not limited to either series or parallel connection. The heat recovered from the CHP unit can be utilised in a wide variety of ways, with the actual configuration chosen depending greatly on the existing plant arrangements and heating requirements.

For example, small-scale CHP units have been successfully integrated with steam heating plant. This has been achieved through two methods:

- by utilising all the heat recovered for heating the boiler feed water or pre-heating the cold feed to steam calorifiers;

- by direct steam raising, from high temperature engine exhaust gases, with low temperature cooling circuits used to pre-heat boiler feed water or the cold feed to steam calorifiers.

5.4 Pump Size and System Balancing

For CHP installations supplying hot water, it is important to establish if existing water pumps have sufficient capacity to pump the required flow through the CHP heat exchangers. CHP unit manufacturers will provide details of minimum and maximum recommended flow rates, together with the associated pressure drop.

After installation of CHP, the flow between boilers and the CHP unit must be correctly balanced. Flow measuring balancing valves are recommended to establish the correct flow rates during commissioning.

5.5 Contaminants in Existing Systems

It may be necessary to reduce the level of sludge and other contaminants in existing heating systems, prior to the installation of CHP.

A number of hospitals have experienced problems associated with old distribution systems. Sludge and other deposits can foul the heat exchangers of the CHP unit, dramatically reducing the heat recovery performance, and problems can occur due to gasification following the recharging of the distribution system after modification.

Every effort should be made to clean up old distribution networks using appropriate proprietary additives/inhibitors and filters. An oversized coarse mesh filter may need to be fitted to filter out the sludge, with progressively smaller mesh sizes being used as the level of sludge is reduced.

5.6 interconnection to Existing Heating and DHW Systems

The CHP unit should be connected to the pipe work of the heating and DHW system using flexible couplings; these are easy to install and have the additional advantage of minimising the transmission of vibrations. All interconnecting pipework should be insulated to the maximum economic thickness.

Isolating valves should be fitted to enable the CHP unit to be disconnected for maintenance without causing interference to the rest of the system. A mesh strainer and dirt pocket should be installed at the inlet to the CHP unit to intercept any debris, and these strainers must be regularly checked and cleaned. Provision must be made for fitting both permanent and temporary instrumentation to permit performance monitoring.

For larger or more complex installations (such as those with steam raising), a number of heating circuits may be required, operating at different temperatures and pressures. For

example, steam may be produced at 8 bar in the exhaust gas heat exchangers, with a separate circuit recovering heat from the engine water jacket to provide pre-heating of boiler feed water. Existing calorifier heater controls may have to be modified to ensure the priority use of the CHP heat source.

5.7 Space-Heating/DHW Control

The existing heating and DHW control system must be fully investigated to determine the optimum CHP control strategy. The conventional method of operating a space-heating system is generally by a time switch and thermostatic control with one of

- simple on/off control on the basis of boiler flow temperature.
- modulating control on the basis of boiler flow temperature.
- compensated hot water circuit with a three-way valve regulating the flow temperature based upon the prevailing outdoor temperature.

In the majority of cases the CHP unit will become, in effect, the lead boiler and if it is satisfying all the heat load then any other boilers will not fire. The optimum method of controlling small-scale CHP units is to regulate them on the basis of the return water temperature, leaving the boiler flow water temperature to float according to demand. In this way the flow temperature will rise to the permitted maximum, to ensure that the return temperature is maintained at, or rises to, the maximum permissible CHP inlet temperature (usually about 70 - 80°C). When the return temperature rises to the maximum permitted level, the CHP unit will shut down automatically.

Alterations to the existing space-heating/DHW system are generally neither difficult nor expensive to achieve. A new sensor and pocket will be required on the return, and a sequencer will need to be wired in, with the CHP unit controlled as the lead heat source. It may be advisable to consider wiring in 'hold off' timers to the boiler(s), to prevent their premature operation in the event of a short term drop in return temperature, which the CHP unit may be capable of overcoming within a short period of time.

If the heating services are controlled by a BEMS, it is advisable to integrate the CHP control and monitoring with the BEMS. This will permit plant operation to be fine tuned to provide optimum performance.

Large scale CHP systems require careful design and specification to ensure satisfactory integration with the existing control systems, and specialist advice should be sought.

5.8 Interfacing with the Electrical System

The majority of CHP units will be connected into the low voltage electrical system. Where connection into the high voltage system is contemplated, it is essential that specialist advice is sought at an early stage. An example of each type of connection is given in Fig 11. Before either connection, a formal agreement must be entered into with the relevant REC to ensure that the proposed interconnection satisfies their requirements in accordance with the Electricity Supply Regulations 1988. This agreement with the REC must include the means of synchronisation between separate sources of supply.

Reasonable precautions must be taken when connecting CHP to ensure that safe conditions are maintained throughout the whole system. These precautions include ensuring compatibility between the means of earthing the CHP unit and that of the existing system, to ensure safety when any neutral point of apparatus operated within the system becomes disconnected, particularly those at high voltage.

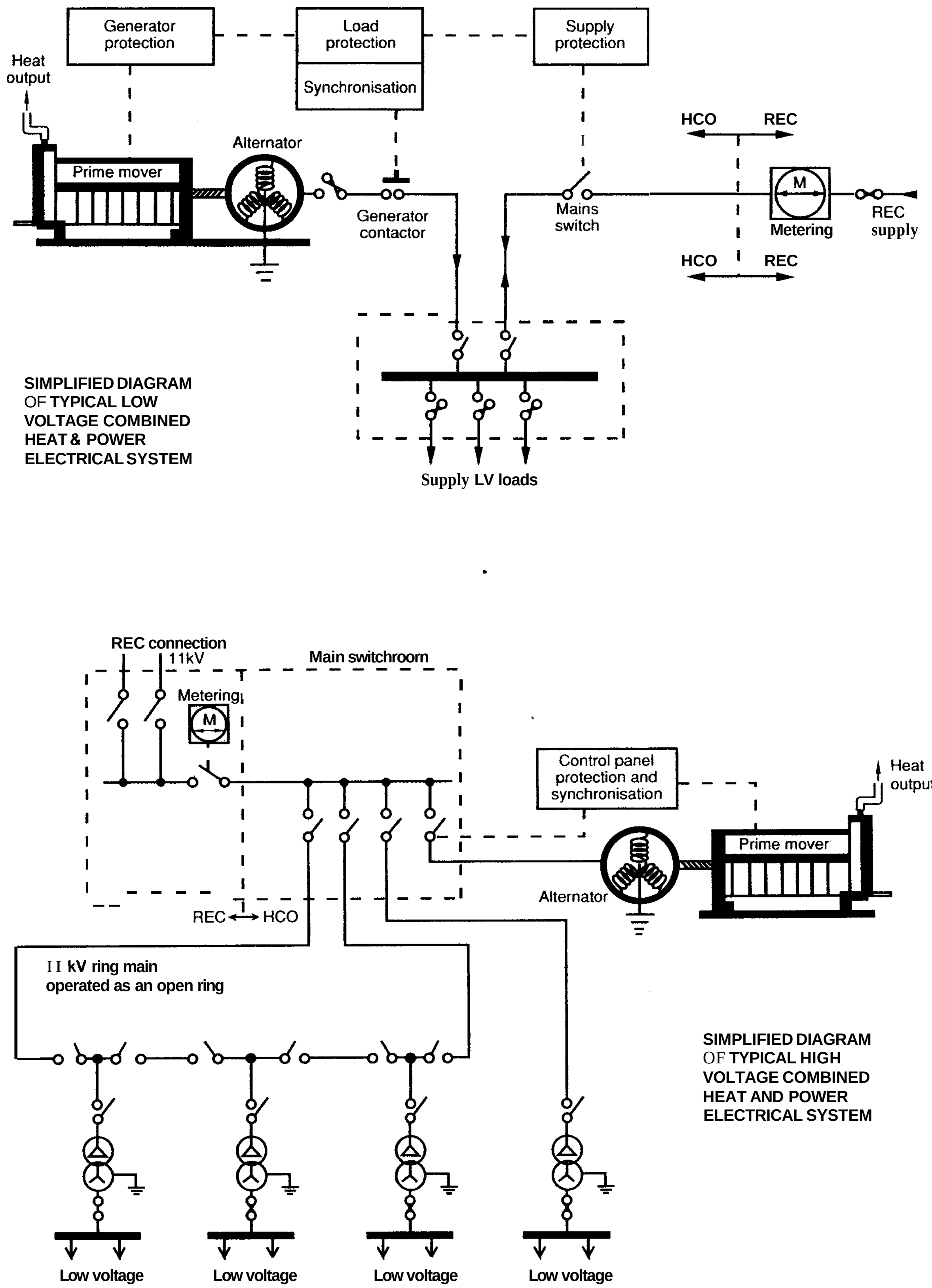


Fig 11 Typical electrical connection arrangements

The CHP connection must meet a number of regulations and recommendations, the main one being the Electricity Association Engineering Recommendation G59/1. .Other statutory requirements relating to electrical safety and recommendations such as the IEE Wiring Regulations for Electrical Installations (16th edition) and Engineering Technical Report ETR113 must also be complied with. Refer to Appendix 3 for a full list of statutory requirements.

5.8.1 *Reinforcement of the Existing Distribution System*

The existing distribution network comprising high and low voltage switchgear, cables, fault limiting reactors, transformers and so on, will require reassessment when CHP is introduced. Depending on the location of the CHP unit, the normal current flow may be reversed and possibly increased in certain sections of the distribution system. This applies both to the normal load and to any prospective fault currents, so the rating of existing equipment which will form part of the CHP installation must be reviewed.

The implications of the Electricity at Work Regulations 1989 should be fully examined, since the economic case for the installation of a CHP system may be adversely influenced if remedial work, associated with upgrading the electrical system to satisfy the new regulations, is required earlier than planned as a result of carrying out work on the system.

Under the Electricity Supply Regulations 1988, a hospital generating electricity is defined as a 'supplier'. Reference should therefore be made to Regulation 26 "Interconnected Supplies", and Parts 1 and 2 of Schedule 3 of the Electricity Act 1989.

5.8.2 *Interconnection and Distribution within the Low Voltage System*

Connections to a low voltage network or system are relatively simple, with protection being limited to overcurrent/earth fault and preventing the machine from 'motoring' if engine failure occurs.

As a general rule asynchronous generators need mains excitation and therefore cannot be used as standby plant. These machines must be taken off line and the independent standby unit started in the event of mains failure. Synchronous generators must be run up to speed to establish the correct voltage and frequency prior to connection to and synchronisation with the mains supply voltage, frequency and phase. Most synchronous generators are equipped with an automatic means of synchronisation.

Where the load is partly supplied from the mains and partly from the CHP generator, loss of mains could result in a generator overload, and the use of high speed protection devices to detect loss of a mains supply is recommended. This protection is essential where power can be exported to a failed supply network.

Particular attention must be paid to system earthing which must comply with the Electricity Supply Regulations 1988. Guidance on alternative earthing arrangements can be found in Engineering Technical Report 113 1989 (see Appendix 3).

5.8.3 *Interconnection to Low Voltage System with Transformer Coupling to the High Voltage System for Distribution*

If this mode of operation is being considered, detailed consultation with, and the written approval of, the relevant REC is essential, combined with a thorough appraisal of the electrical safety rules applied to the system.

Generally, before a CHP installation is interconnected with the supply network, it must be established that suitable protection is afforded to avoid adverse effects on the network and to protect other consumers connected to the network. Voltage, frequency and symmetry

(assuming a 3-phase system) of the output must be maintained within the limits imposed by the statutory requirements.

Under network fault conditions, the CHP unit must be prevented from continually feeding into a fault or feeding onto a high voltage, unearthed network. Where the CHP generator is operating on a low voltage system and it is possible to export power via a distribution transformer to a higher voltage system, precautions must be taken against rising voltage levels. It is normal practice to restrict the transfer of power through **a** transformer in the reverse direction to some 70 to 80% of its full load rating.

5.8.4 *Direct Connection to the High Voltage System*

The decision to connect a CHP installation into an existing high voltage network is normally confined to larger size units (i.e. 500 kWe and upwards), where a substantial level of power can be used with a steady load factor over a 24-hour period. Under these conditions it is likely that at times of reduced demand the excess power can be exported to the supply system.

High voltage units are almost always of the synchronous generator type, having facilities for direct synchronisation onto the supply network. Precautions must be taken to limit the combined fault levels, and to offer protection to both the CHP unit and network. Synchronous machines can be used for standby power in the event of mains failure; however, precautions must be taken to ensure that a CHP unit is not allowed to feed into a failed network, as this would seriously overload the unit and cause a shutdown, resulting in total loss of power to the hospital installation.

For high voltage systems with neutral earthing the relevant REC may use direct, resistor, reactor or arc suppressor coil methods to connect the system to earth. To comply with the Electricity Supply Regulations 1988, agreement must be reached on the provision and compatibility of connecting the two systems with earth. **All** reasonable steps must be taken to avoid unearthed operation by installing suitable protection equipment to detect the loss of the REC supply. Provision must also be made for the system to remain safe should any neutral point in any apparatus operated at high voltage that is connected with earth become disconnected.

If the CHP unit is connected to the relevant REC system designed for multiple earthing, earthing may be achieved by the use of a busbar earthing the transformer or the star point on the generator. Alternative arrangements are shown in Engineering Technical Report 1 13, as published by the Electricity Association.

The introduction **of** high voltage generation to a hospital's high voltage network, other than at the point of REC supply via a dedicated circuit breaker arrangement, requires careful consideration and specialist advice must be sought.

5.8.5 *Projected Load Factors*

In order to be viable electrically, the CHP unit must run under full load conditions for 80 - 85% of its operational life. Operating a CHP unit at less than full load, either by reducing output or by modulation, reduces its efficiency and shortens its working life; the operational load factor must therefore be as near to unity as possible. The export of excess power can help in situations where the available electrical energy cannot be used locally.

5.8.6 Interconnections to Load Centres

Ideally the CHP unit should be located at the electrical load 'centre of gravity' to reduce the length of any connecting cables: however, the utilisation of the recovered heat often dictates the actual siting of the plant. On a site having separate buildings, the installation

costs of the interconnecting cables can be quite substantial, and must be taken into account when assessing the overall project.

From an electrical perspective, the optimum solution is to locate the CHP unit next to the main incoming switchgear, where the interconnection can be made directly into the existing distribution system. If for some reason this location cannot be used, then a number of smaller units located at the various load centres may provide a solution enabling power to be transferred via the existing distribution cabling.

5.8.7 *System Fault Levels*

When a CHP unit is connected into an existing distribution system, consideration must be given to the combined short circuit fault levels. A calculated assessment will have to be made to establish the magnitude of the combined prospective fault current at any point within the network. This assessment will involve the summation of all circuit impedances, together with the direct axis sub-transient reactance of the generator. Such an assessment, when checked against the known circuit parameters, may reveal the necessity of increasing the switchgear and/or distribution cable fault ratings.

The CHP unit will form an essential part of the electrical system and as such must be protected against faults arising within the CHP installation itself as well as in any other part of the system. The following points provide a checklist of the fault conditions which must be allowed for:

- Voltage Protection

  The output voltage must remain within stated limits, and therefore relays or solid-state devices should be connected to monitor the output of all phases, which will cause the generator breaker to open and the machine to lock-out if deviation from the limits is detected. These actions should also generate alarms, which should be relayed to a local annunciator, or to a remote control centre and/or be transmitted over a telemetry highway.

  When the machine locks-out, automatic load shedding can be arranged to ensure that essential loads are maintained on whatever supply remains available.

- Frequency Protection

  Over/under frequency devices should be connected to monitor the frequency of the output, which must not go outside the range 48.0 - 50.5 Hz for a period of six or more seconds. In the event of over/under frequency output, the generator breaker will be opened and the machine locked-out as in the above case.

- Loss of Supply

  If the CHP unit is required to run during periods of loss of REC mains supply, special precautions must be taken.

  On loss of mains supply, a mains excited asynchronous generator must be disconnected immediately by a phase failure relay, and must only be restarted after restoration of the mains or when the excitation current can be provided by a synchronous standby generator. The incoming supply circuit breaker must be opened and the connected load reduced to within the capacity of the generator.

  Synchronous machines can continue to operate after mains failure, but the incoming supply breaker must be opened to prevent back-feeding onto a failed supply system. If the generator cannot supply the full installation load, then load shedding is required.

To monitor the incoming mains supply, suitable relays must be used to detect the mains as distinct from the CHP output.

- Phase Failure

  The symmetry of a 3-phase supply must be monitored to guard against the CHP unit generating into a supply system where any one phase has failed, and creating artificial phase conditions. Phase failure should be treated as a loss of mains supply, with the incoming breaker tripping on detection of a failure.

  With one phase failed, an asynchronous machine would continue to generate a 3-phase voltage output, but the system would be unbalanced, tending to generate unbalanced currents. In this case the CHP unit must be taken out of service and alarms raised.

  Under the same conditions, a synchronous machine would continue to generate as normal, but the loading would be unbalanced due to the machine feeding into the faulty phase. In this case the faulty mains supply should be tripped out and the CHP unit allowed to supply the essential loads only. On restoration of the mains supply, the CHP output must be re-synchronised with the incoming mains. Automatic means are available to undertake this function.

- Earth Faults

  Line-to-earth and line-to-neutral faults, either internal to the generator or external on another part of the installation, produce zero phase sequence fault currents which unbalance the system. These faults are detected by various in-circuit devices, which trip the generator or mains supply, possibly with an attendant time delay. Dedicated instantaneous devices can be used which afford adequate discrimination, isolating a faulty section and leaving the healthy circuits in operation. These in-circuit devices need to be connected at appropriate locations in the distribution system.

- Overheating of Generator

  Problems of overheating are usually associated with conditions of overcurrent, which are dealt with by overcurrent devices. However, internal winding faults, unbalance and mechanical faults can lead to overheating. With smaller CHP units it is convenient to monitor the temperature of the windings using embedded thermistors; larger units usually have more sophisticated protection.

- Loss of Control System

  CHP control systems can be very sophisticated, and control malfunction could result in the catastrophic failure of the whole installation. It is therefore recommended that the design of the control system logic is based on a ‘fail-safe’ approach, and includes control system monitoring, so that in the event of a failure, the overall system is locked-out and alarms raised.

  Most control functions are achieved by using solid-state components in the form of ‘programmable logic’ devices, using computer techniques, where the logic has built-in monitoring facilities offering a fully integrated, self-monitoring fail-safe control system.

5.9 Optimising CHP Unit Operation

The importance of optimising the operation of the CHP unit is discussed in more detail in Appendix 1. In summary, two main operating regimes exist:

- Regime 1

  The CHP unit is operated to provide base load electricity and thermal output, with any shortfall being supplemented by electricity from the grid and hot water and/or steam from boilers.

- Regime2

  The CHP unit is operated to provide electricity for export, with the recovered heat being used on site.

For both of these regimes a microprocessor-based control system (or the constant attendance of skilled plant operators) will be required to determine when, and for how long, the unit should operate.

Two further options in which the CHP unit is either operated to provide site electricity, with part or all of the recovered heat being 'dumped' (i.e. rejected to atmosphere via heat exchangers), or is operated to export electricity with recovered heat being dumped, are unlikely to be economic unless a very cheap source of fuel (e.g. landfill gas) or unusually attractive export tariffs are available.

The importance of establishing the correct operating regime and control strategy for the CHP unit cannot be over emphasised. The optimum regime for each site will be different and will depend on:

- import and export tariffs;
- cost of fuel;
- efficiency of existing heating plant;
- maintenance costs:
- other CHP incremental costs (e.g. lubrication, auxiliary power requirement).

For example, electricity generation with heat dumping may be cost effective (after making due allowance for fuel, maintenance and other costs) only during periods when Maximum Demand (MD) or very high Seasonal Time of Day (STOD) charges apply. It is important that the CHP unit is **not** permitted to operate when these conditions do not prevail, such as at night or when a low cost import tariff is available.

5.10 CHP Unit Control and Monitoring

The function of the CHP control system is to control the start-up and shut-down sequence of the unit, as well as monitoring the mechanical and electrical conditions during normal running and providing on-line fault diagnosis. Control systems range in sophistication from relay logic and solid-state systems, to full microprocessor control with remote communication facilities.

The actual start-up sequence will depend on the unit manufacturer and the degree of sophistication offered: some units provide pre-circulation of oil, and battery starting with full system proving before on-load operation.

On shut-down, all units must be disconnected from the mains supply and fuel supplies must be cut off, but the water pumps may continue to operate until the engine block has cooled sufficiently. Again the exact sequence of events will depend on the preferences of the CHP installation designer and the size of CHP unit.

5.10.1 *CHP Unit Monitoring*

Instrumentation provided with the **CHP** unit should provide adequate facilities for long term monitoring, including direct measurement of waste heat recovered.

While the **CHP** unit is running, the control system monitors the various sensors that will cause shut-down if a fault is detected. For example, on a typical gas-fuelled engine these sensors may include:

- interlocks with heating system pumps;
- flow switches in pipework;
- control and limit thermostats;
- low engine oil pressure;
- emergency over-temperature thermostats;
- low gas pressure;
- high gas pressure;
- overspeed sensor;
- low speed protection;
- electrical power overload.

When any of the parameters measured by these sensors goes outside preset limits, the **CHP** unit will generally shut down and a visual alarm will be activated. The unit will not restart until manually reset; this is termed a ‘lock-out’. Some units may attempt one or more restarts before lock-out occurs, either after a set time interval or when the condition has cleared.

6. ECONOMICS AND FINANCING

This section of the guide contains two main parts: financial evaluation techniques and CHP financing options

6.1 Financial Evaluation Techniques

A wide range of analytical techniques can be applied to assess the economic feasibility of a CHP scheme. Two methods have particular relevance to the Health Service:

- **Simple payback** (see Tables **3** and **4)**

  This value is the ratio of capital cost to annual cost saving, and provides a quick and rough assessment of the relative merits of proposed schemes. However, a more sophisticated approach is required if the full effects of future revenues and costs are to be assessed.

- **Benefit** Cost **Ratio (BCR)** (see Tables 5 and 6 and Fig 12)

  BCR is a mathematical method, which uses the Discounted Cash Flow (DCF) technique to compare schemes for their financial viability. The BCR method is strongly recommended in preference to simple payback calculations, by HM Treasury and the Department of Health. *The system **is** not confined **to** energy saving and **is** recommended for any comparative proposals.*

BCR is preferred over other methods because it allows a more accurate appraisal of cost saving measures, allowing for changes in monetary value over time, and also brings the various component parts, with varying lifetimes, to a common and comparable base. Future and recurring capital costs, revenue, energy costs and savings, and changes in fuel costs can all be allowed **for** in the calculation.

> ENCODE (the NHS Energy Code developed by NHS Estates in conjunction with the NHS Energy Policy Group) includes a suite of computer programs which form a specific package, ENCOST, especially devised to help with investment appraisals. This package can be used to assess the costs and benefits of proposed measures, and to create a programme of work to implement the chosen measures, as described in the ENCODE Manuals (see Appendix **4).**
>
> When calculating the BCR, each 'measured item' must be identified separately, and its cost or benefit individually discounted back to its Net Present Value (NPV). These are then combined with those of other 'measured items' to give a BCR for the entire measure. Measures with higher BCRs are the most cost effective; those with a BCR of less than one have no positive cost advantage. The interdependency of energy saving measures can also be assessed using BCR techniques.

Undertaking a detailed financial appraisal is a time consuming exercise. For this reason it is recommended that simple payback is used to derive a short list of options, with a more detailed financial appraisal, such as BCR, then being undertaken to identify the best solution. Detailed appraisal is particularly important if a large or complex scheme is being considered.

Simple packaged CHP units, intended for base load operation, do not generally require highly detailed analysis to establish their potential revenue savings, and the calculation of simple payback time is often sufficiently accurate to distinguish between the more or less profitable options, although BCR should be calculated for the preferred scheme to justify the investment required.

Table 3 Simplified method for calculating CHP payback period

Electricity displaced (p/hour) = CHP unit electrical output(kWe) x imported electrical tariff (p/kWh)

Boiler fuel displaced (p/hour) = (CHP unit heat'output (kW) x 100) x existing boiler fuel price (p/kWh)
boiler efficiency (%)

COSTS

Fuel input costs (p/hour) = CHP unit fuel input (kW) x CHP unit fuel price (p/kWh)

Maintenance cost (p/hour) = CHP unit electrical output (kWe) x maintenance cost (p/kWhe)

VET BENEFIT

Vet benefit (p/hour) = total savings (p/hour) - total costs(p/hour)

Annual saving (£/year) = annual hours of equivalent full load operation (hours) x net benefit (p/hour)
100

Payback period (years) = total system installed cost (£)
annual saving (€/year)

1 Any additional savings (or costs) can be evaluated as above. For example:

Income from export of surplus electricity to the grid = export output (kW) x export tariff (p/kWh) x hours per year

2 Maintenance costs are generally expressed by manufacturers in terms of p/kWh of electrical output.

3 The existing boiler fuel cost is used to determine the saving (in the calculation of 'Boiler fuel displaced'), since the CHP system may use a higher cost fuel.

Conversion factors

It is important that the correct units are used for fuel costs. All fuel costs should be converted to p/kWh using the following conversion factors:

Fuel (cost/unit of supply)	Conversion factor to **p/kWh**
Gas:	
Natural gas (p/therm)	cost/29.31
Natural gas (p/ft^3)	cost/0.30
Natural gas (p/m^3)	cost/10.73
Propane (p/litre)	cost/6.96
Butane (p/litre)	cost/7.85
Oil:	
Diesel (p/litre)	cost/10.22
Gas oil 'D' (p/litre)	cost/10.58
Light fuel oil 'E' (p/litre)	cost/11.22
Medium fuel oil 'B' (p/litre)	cost/11.28
Heavy fuel oil 'G' (pilitre)	cost/11.42

NB The above conversion factors are based on the gross calorific value of the fuel.

Table 4 Example evaluation of CHP payback period

The example evaluation provided below is for a gas-fired CHP system having a thermal output of 254 kWth and an electrical output of 162 kWe. The boiler fuel being displaced is natural gas.

Electrical output					162 kWe
Heat output					254 kWth
Fuel input					610 kW
Electricity price					4.75 p/kWh
Interruptible gas price					20.0 p/therm
Boiler efficiency					75%
Maintenance cost					0.70 p/kWhe
Annual hours equivalent full load					6,000
Total system cost					E101,950
SAVINGS					
Electricity displaced	162	x	4.75	-	770 phour
Boiler fuel displaced	$\frac{254}{0.75}$	x	$\frac{20.0}{29.31}$	-	231 p/hour
∴ Total savings =	1,001 phour				
COST					
Fuel input	610	x	$\frac{20.0}{29.31}$	-	416 p/hour
Maintenance	162	x	0.70	-	113 p/hour
∴ Total costs -	529 p/hour				
NET BENEFIT					
Net benefit -	1,001	-	529	-	472 p/hour
Annual hours equivalent full load operation				-	6,000 hours/year
Annual savings =	$\frac{6{,}000}{100}$	x	472	=	**£28,320/year**
Paybackperiod =	$\frac{\text{systemcost}}{\text{annual savings}}$	=	$\frac{101{,}950}{28{,}320}$	=	3.6 years

Table 5 The comparison of energy measures for two projected District General Hospitals in Wales, as reported at the budget cost stage

OPTION	HOSPITAL 'A'	HOSPITAL 'B'
1 Buildings management system	**£88,600**	**£94,900**
2 Services, sub-metering	**£76,100**	**£61,300**
3 Combined Heat & Power (CHP)	1 x 600 kW set gas engine 1 x 450 kW set gas engine 1 x 600 kW diesel generator BCR = 4.30	2 x 300 kW set gas engine 2 x 300 kW diesel generator BCR = 2.44
4 CHP waste heat - thermal store	BCR = 1.04 **£48,400**	BCR = 1.51 **£62,355**
5 Partial ice storage	Self-funding -	BCR = 1.45 **£78,285**
6 Improved thermal insulation	BCR = 2.39 **£42,000**	BCR = 1.45 **£31,650**
7 Condensing boiler plant	BCR = 2.5 **£51,900** gas-fired, 30% total load	Not recommended with selected fuel 3,500 sec oil
8 High frequency lighting fittings	BCR = 1.29 **£168,775**	Not considered
9 Extract ventilation - heat recovery	Plate heat exchange preferred BCR - 1.02	Plate heat exchange BCR = 1.71
10 Improved 'U' to external wall	BCR = 1.13 'U' = 0.3 W/m^2K	BCR = 1.85
11 Improved 'U' to roof	BCR = 1.05 'U' = 0.3 W/m^2K	BCR = 1.58
12 Draught lobbies	BCR = 2.22 **£61,000**	BCR = 0.29 **£10,000**
13 Double glazing	BCR = 1.22 **£223,000**	To be funded from District Current Account (DCA)
14 Perimeter ventilation	Not recommended	Excess cost not examined in detail **£779,000**
15 Departmental relationships (location for energy conservation)	Whole hospital considered	Energy centre considered

The values in bold are the capital costs for the energy measure concerned.

Table 6 Worked example of a BCR calculation (based on Hospital 'A' in Table 5)

The multipliers used in this example are dependent on the system used for calculation of net present values (NPVs), and have been calculated using the following assumptions (as directed by current guidance):

- Test Discount Rate - 6%
- Increase in fuel costs in real terms - 3.5%
- Building life - 60 years

Characteristic	Period/Interval	Multiplier
Annual costs		16.21
Recurring energy costs	Annual	30.69
Regular recurring costs	5 years 10 years 15 years 20 years 25 years	2.75 1.16 0.64 0.39 0.25

The economic life of plant items has been devised from Table B18.2 of the CIBSE Guide, 1986.

Procedure:

1. Express all costs as NPVs (NPV (COSTS)).
2. Express all benefits as NPVs (NPV (BENEFITS)).
3. Calculate the BCR.
4. If BCR > 1, scheme is economic.
5. If several schemes are being considered, rank them in priority according to BCRs.

Calculations for CHP	NPV (£)
COSTS:	
1 NPV OF INSTALLATION 1 x CHP Unit - 450 kW electrical output 1 x CHP Unit - 600 kW electrical output Total NPV (including project overheads & installation)	550,585
2 NPV TO REPLACE CHP INSTALLATION IN 20 YEARS £339,490 x 0.39 (replacement of prime movers only)	132,401
3 NPV OF REGULAR MAINTENANCE COST **£5,269/year** x 16.21	85,410
4 PRESENT WORTH OF BUILDING Extra over	403,500
∴ **TOTAL NPV (COSTS)**	**1,171,896**
BENEFITS:	
1 NPV RESULTING FROM DAYTIME SAVING ON NATURAL GAS £164,321/year x 30.69	5,043,011
∴ **TOTAL NPV (BENEFITS)**	**5,043,011**

$$\text{BCR} = \frac{\text{NPV (BENEFITS)}}{\text{NPV (COSTS)}} = \frac{5{,}043{,}011}{1{,}171{,}896} = 4.30$$

The scheme is therefore an excellent investment.

(Multipliers for different criteria can be determined by reference to ENCOST - see Page 37)

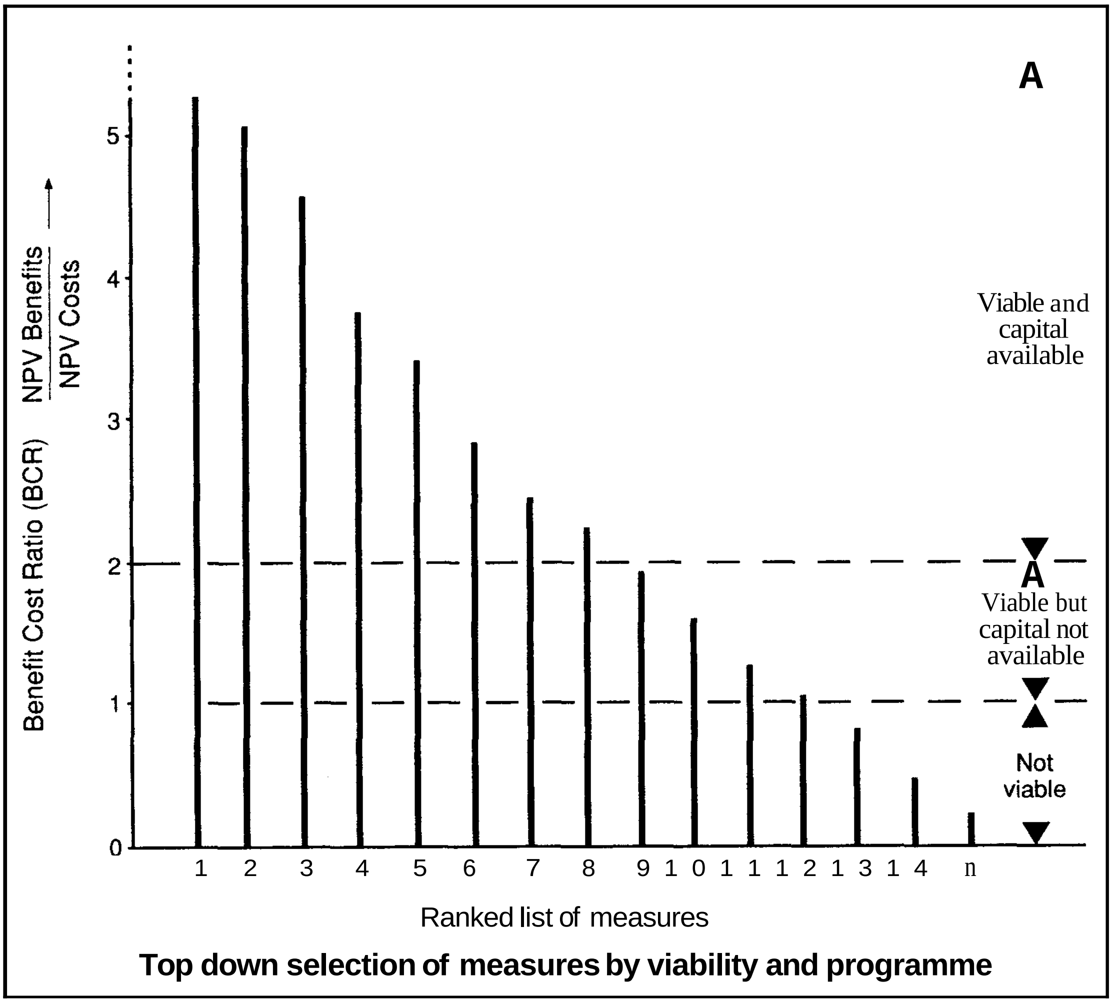


Fig 12 Ranking of energy saving measures by viability and programme

6.2 Costs and Benefits of CHP

In order to determine the net benefits of a CHP scheme in the Health Service it is necessary to account for all the associated costs and benefits. Revenue generated by the sale of electrical power, steam or heat, or the reduction of Maximum Demand (MD) charges, can substantially enhance the economic case for CHP.

A number of the major cost components can be determined with sufficient accuracy during the detailed design stage of the project. Some costs and benefits may be difficult to quantify (such as maintenance, major overhaul cost and frequency), and information regarding anticipated import and export tariffs may be difficult to obtain. Where appropriate, the ‘avoided cost’ associated with the displacement of a conventional emergency standby power plant should also be carefully evaluated, and the avoided cost of boiler replacement/expansion should also be examined.

The cost associated with grid connection and protection should be fully assessed, as it may be significant. The cost can also vary significantly depending on the circumstances and locality. Consultations with the relevant REC should be undertaken at the earliest opportunity.

Although it is difficult to put monetary values on the environmental benefits of CHP, these should nevertheless be considered in the option appraisal (see Section 2.3).

6.2.1 *Maintenance Cost Evaluation*

The maintenance of CHP units is more expensive than conventional boilers, and it must be taken into account when calculating savings. Current experience suggests that overall maintenance costs for packaged CHP units will lie in the range 0.5 - 0.75p/kWh of electricity generated. The manufacturers should be consulted for the actual figure, but as a guide 0.7 p/kWh can be used as fairly typical. The actual figure will depend on the unit location, size and in-house resources. Large integrated CHP systems can have maintenance costs below 0.5p/kWh (e.g. gas turbine based systems), with the actual value dependent on the complexity of the system and the level of manning required.

It is essential that proper comparisons are made between the systems being considered and, to facilitate this, life cycle maintenance costs should be carefully established with the CHP unit manufacturer or system designer. The life cycle costs should include routine service and lubrication costs as well as top-end and complete overhaul costs, all on an annual basis.

For the less expensive automotive derived engines, a complete overhaul is normally required after 15,000 - 20,000 hours of operation and this may include replacement of the engine block. With the more robust and expensive industrial engines a complete overhaul would be required after 20,000 - **30,000** hours of operation and would typically comprise replacement of camshafts, pistons and liners. Therefore, a comparison of costs over a period of at least 25,000 hours operation should be undertaken. The maintenance costs will also depend on the level of service required, which can range from using in-house staff to undertake basic servicing tasks, to having a fully-inclusive maintenance service agreement incorporating emergency call-out.

The costs associated with gas turbine maintenance vary from 0.2 - 0.7 p/kWh depending on the type of maintenance agreement adopted. Some contractors and manufacturers provide an extended warranty scheme covering parts and labour, which transfers a significant proportion of the risk associated with long term maintenance costs to a third party.

6.3 CHP Financing Options

Three main options exist for financing a CHP scheme:

- outright purchase by the hospital;
- leasing/discount energy cost schemes;
- Contract Energy Management (CEM).

Maintenance responsibilities and costs vary between options. In addition, the commercial and contractual terms and conditions can be very complex, especially for discount energy cost and CEM schemes, and a number of energy consultants specialise in providing advice to hospitals regarding schemes of this nature. These consultants undertake a full CHP feasibility study (if required) and also prepare the tender documentation, together with post-tender evaluation and contract supervision.

6.3.1 *Outright Purchase*

Outright purchase is still the most common method of obtaining a CHP system. Many hospitals are able to fund small-scale CHP schemes as a result of savings achieved from other energy saving measures (i.e. funded from the local revenue budget). However, if capital is not available for investment in a CHP scheme, or if considerable delays in obtaining the finance are likely, it is strongly recommended that discount energy cost or CEM options are considered (see Sections **6.3.2** and **6.3.3).**

Plant is generally purchased directly from the equipment manufacturer for small packaged systems, or via specialist subcontractors for larger installations. Also, a number of RECs have recently established joint venture companies with equipment manufacturers.

When comparing quotations for the supply of CHP plant, particular attention should be paid to the maintenance and warranty agreements, the terms of which vary widely between suppliers. Small packaged units are often supplied with the first three years' maintenance (parts and labour) included in the price.

CHP installations will have to compete with other projects requiring capital investment on the basis of merit (i.e. value for money), and it will be necessary to produce a BCR analysis for any proposed scheme. Equipment suppliers and/or consultants will generally help in the preparation of the financial evaluation and option appraisals if hospital manpower resources are limited.

6.3.2 Leasing/Discount Energy Cost Schemes

Most CHP manufacturers can arrange finance to permit plant rental, leasing or hire purchase. A wide range of leasing/rental arrangements are available and considerable care is required to determine the most cost-effective option. It should be noted that some of the leasing schemes available could be considered as unconventional finance, subject to close scrutiny by HM Treasury, which could lead to total expenditure control adjustments; the guidelines for this are given in Section 6.3.4.

- Discount electricity schemes

  A number of CHP manufactures operate a discount electricity scheme which involves little or no risk for the hospital; the hospital simply makes space available for the CHP unit. This is sometimes referred to as the 'Black Box' approach. Many variants of discount electricity schemes exist, and these no cost/no risk schemes are becoming increasingly popular with hospitals as a revenue earning/saving opportunity (i.e. not primarily for energy saving reasons). The following points summarise most discount electricity schemes:

  - The hospital enters into a contract (normally **5** years) with the equipment supplier/ manufacturer for the supply of discount electricity.
  - The equipment supplier/manufacturer provides a complete packaged system and pays all installation costs.
  - The hospital pays for all the fuel used by the CHP unit, but all recovered heat is available at no additional cost.
  - The hospital pays the CHP supplier/manufacturer for all the electricity produced, at an agreed discounted price, and retains all the savings in electrical cost provided by the discounted electrical supply. The discount electricity price (and hence saving) is linked to the local REC published supply tariff and is reviewed annually.
  - The annual savings achievable via a discount electricity scheme are likely to be about 20-25% of the savings provided by outright plant purchase (as a result of the financing cost and transfer of risk to the plant supplier).
  - The CHP unit is less efficient than a boiler as a provider of heat, reducing the value of the savings provided by the discounted electricity consumption, which must be taken into account when determining the net saving for viability.
  - The maintenance cost element of the discount electricity price is linked to an agreed index.
  - Plant is generally run at all times, except when night-time or other low import tariff rates apply.

- The hospital is **not** normally contracted to operate the plant for a minimum number of hours per year. However, in some cases the plant supplier/manufacturer will guarantee a minimum annual saving, provided that the hospital agrees by contract to operate the plant for a minimum number of hours each year.
- Levels of risk to the hospital are very low - the supplier/manufacturer is liable for all capital and maintenance costs. In the event of plant failure (caused by non-availability of the engine) many discount electricity schemes will compensate the hospital for any lost savings.
- The hospital can purchase the CHP unit at any time during the contract period. Many hospitals decide to purchase the CHP units after one or two years of operation, to obtain the full cost savings benefits themselves.
- Most discount electricity schemes are not viewed as unconventional finance and as a consequence do not require HM Treasury approval (since no hospital capital is required and plant ownership and maintenance responsibility always remains with the supplier).

- Discount heat schemes

  Discount heat schemes are a recently introduced option for discounted energy purchase, and therefore the full benefits of these schemes have yet to be evaluated. Under discount heat schemes, proposed by a CHP manufacturer in joint venture with several RECs, a contract is arranged with the hospital for the supply of heat at a discounted price. The hospital pays for all the fuel used by the CHP unit and also for all heat produced at an agreed discounted price, fixed in relation to electricity consumption. All electricity generated is made available free of charge, with any excess electricity purchased by the local REC. All other discount heat arrangements are similar to those of discount electricity schemes, listed above.

6.3.3 Contract Energy Management (CEM)

A number of CHP systems have been installed in hospitals as part of larger CEM agreements. CEM has been viewed as a source of unconventional finance and this has limited its take up in the NHS. Guidelines were issued by the Department of Health in 1989 and the HM Treasury/Department of Energy in 1990 which have helped to clarify the position of CEM.

CEM provides a method of obtaining some of the benefits of CHP without having to invest capital. Typically CEM contracts are arranged with the costs financed from revenue savings, and with ownership of the CHP scheme being transferred to the hospital at the end of the contract.

Other benefits include the transfer of some or all of the risks from the hospital to the contractor. The contract defines whether the client or contractor is responsible for:

- capital overspend;
- time delay;
- poor plant performance;
- fuel price variations;
- manpower costs;
- maintenance.

The degree of risk transferred to the contractor will substantially influence the cost of the service provided.

- ***Evaluating CEM Proposals***

  Considerable care is required when comparing CEM contract offers and the hospitals should specify the information to be contained in the tender documents in order to simplify comparison. In addition to the technical detail of the proposed CHP scheme, the following contractual information is of particular importance:

  - Annual payment to contractor split between capital and service elements (i.e. annual contract sum).
  - Payment terms required (such as 12 monthly payments or a single annual payment in advance).
  - Contract term (i.e. length of contract).
  - Equivalent interest rate (APR) for the capital element of the annual contract sum.
  - Projected average inflation rate over the length of the contract.
  - Indexing arrangements (i.e. formula for varying the annual payments for fuel, electricity, operation and maintenance).
  - Penalty for early contract termination.
  - Ownership of CHP scheme at the end of the contract term.
  - Maintenance responsibilities and cost (in particular which party is responsible for spares and consumables).
  - Warranty arrangements.
  - *Force majeure* terms and conditions.
  - Penalties for poor plant performance (such as low availability, poor efficiency).
  - Guaranteed minimum annual saving (if any).
  - Which party is responsible for capital overspend.
  - Whether the annual contract sum is reduced if the capital is underspent.
  - Who is responsible for late completion of the installation and what penalties apply (if any)

The indexing arrangements used by some contractors are of particular importance. What may appear very attractive in the first year of the contract can in reality be very expensive if a longer term view is taken. For example, some contractors require that the service and capital elements of the annual payment are linked to an agreed index (e.g. retail price index (RPI)), with the amount payable being increased annually. Although initially the contract may appear to offer a very low cost source of finance, it can prove very expensive when the affects of inflation are taken into account. However, provided that care is taken in evaluating CEM schemes they can represent excellent value for money, and enable projects to be implemented quickly.

6.3.4 HM Treasury Guidelines For CEM and Other Unconventional Finance Packages

The choice between financing options should be based solely on considerations of value for money.

The Treasury will not normally impose expenditure control adjustments unless:

- The capital cost of the project exceeds El million. This represents a CHP scheme having an electrical output of about 1.5 MWe.

- The cost of financing the capital installed is expected to be more than half of the contractor's annuitised annual charges under the contract (excluding any fuel payments to be made on behalf of the client), and the total of all CEMs in any one Department would require an adjustment of more than £250,000.

It should be noted that all schemes having a capital expenditure of over £250,000 should be submitted to the Treasury for approval.

The above arrangements are designed to safeguard value for money, while at the same time maximising the freedom of Departments to pursue CHP financing options.

Small-scale CHP schemes will fall well below the £250,000 threshold. However, medium and large-scale schemes will have to be submitted to the Treasury for approval, which could cause time delays and, if over £1 million (capital), could result in total expenditure control adjustments.

7. CASE STUDIES

The case studies in this section comprise a series of individual schemes which represent the range of CHP installations possible in the Health Service. In general they demonstrate the successful deployment of CHP as both a cost-effective and environmentally beneficial measure. However, two of the case studies present examples of poor installations, together with the lessons learnt from these projects.

Case Study 1: Addenbrooke's Hospital, Cambridge

Site

Addenbrooke's Hospital is a 900 bed acute provincial teaching hospital with a separate maternity unit. The site covers 66 acres, and has a central steam raising boiler plant (dual fuel: gas and gas oil).

CHP Installation

The CHP installation consists of a 3.7 MWe European Gas Turbine (formerly Ruston) Typhoon gas turbine, and has been operating since early 1991 without major problems. The turbine is designed to operate on natural gas, with light fuel oil **(LFO)** as a standby fuel. Electricity is produced at 11 kV in parallel with the grid. The CHP installation is intended to provide the base load electrical requirement with any excess exported to the Pool[5], if the Pool buy-back tariff justifies export. The CHP scheme is designed to recover heat and heat dumping is an additional facility to enable extended running under high ambient conditions. It is intended to operate 24 hours a day **for** 12 months of the year with a 2 week summer shut down for maintenance.

In the event of failure of supply from the grid, the CHP scheme electrical output maintains continuity of the supply, but separate standby plant has been retained.

Fig 13 Gas turbine and exhaust heat recovery system

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5 The Pool is operated by the National Grid Company and provides a market for the sale and purchase of electricity by large electricity producers and consumers.

System Economics

The hospital considered non-NHS funding of the CHP installation, but ultimately decided on outright purchase.

The total installation costs amounted to E1.3 million (£350/kW) with anticipated annual savings of £400,000 per year giving a payback of 3.25 years. However, the first year of operation suggests that the savings are likely to be greater than originally predicted, because it is running for more hours than anticipated. The installation has the facility for running under several different modes of operation. Throughout the year these options have been explored and the most cost-effective has always been the one which provides optimum efficiency of the turbine.

Case Study 2: Hull Royal Infirmary, Hull

Site

Hull Royal Infirmary is part of Hull Health Authority and is an 800 bed acute hospital built in the mid-1960s. It **is** a tower block construction and is located in the city centre.

Its boilers were originally coal fired but were later converted to natural gas. The site also contains **a** major laundry which is a large steam user and is located near to the boiler house.

Hull Health Authority already has extensive CHP operational experience, having installed a 40 kWe, Combined Power Systems Ltd (CPS) unit in 1989. This unit operates on a discount electricity scheme (see section 5.3.2) and as a result of its successful operation, a new larger scheme has been specified.

CHP Installation

The contract for this new installation was awarded, after competitive tender, to British Gas North Eastern with Base Load Systems Limited nominated as its specialist CHP sub-contractor.

The installation produces 650 kW of electricity, 450 kg/hr (1000 lbs/hr) of high pressure steam at 13.8 bar **g** (200 p.s.i.g.), 570 kW high temperature hot water at 126°C, and 121 kW of hot water at 90°C. The installation is located in the Infirmary's boiler house and comprises:

- Caterpillar 35 12 spark ignition gas engine and alternator
- Waste heat recovery boiler and heat exchangers
- Control panel and monitoring system
- Acoustic enclosure, associated piping and cabling

The **CHP** plant is supported by a maintenance and monitoring package which includes labour and parts for the whole system.

System Economics

The CHP installation supplies 85% of the hospital's total electricity requirement and approximately 50% of its heat requirement. The current annual value of the replaced electricity is £200,000 and that of the heat is £70,000 gross. These yield net savings of £150,000 per year after fuel and maintenance costs, and give a payback based on current electricity and gas tariffs of 2.5 years.. General management of the hospital are looking forward to being able to redirect these significant savings into patient care.

Case Study 3: Royal Hospital and Home, Putney

Site

The Royal Hospital and Home is a 300 bed independent charitable hospital for severely disable people. The hospital is housed in a modernised Victorian building, with three new wings having been built over the last ten years.

The existing energy systems consisted of a central boiler house with three modem 586 kW dual fuel fired boilers. In addition, the hospital laundry was served by two 702 kW steam boilers, and the Nurses' Home by two 220 kW oil-fired boilers.

CHP Installation

The CHP installation was part of a larger BP Energy CEM agreement which comprised a number of energy saving measures, including: the replacement of the old oil-fired boilers in the Nurses' home with six modular 50 kW boilers; the installation of heat recovery in the hospital laundry; site zone control; and the introduction of energy efficient lighting. Two Applied Energy Systems (AES) (now SPP Energy Ltd) 40 kWe 'Mini CHiP' CHP units were installed in the main boiler house in 1985. The original feasibility study suggested that the demand for electricity and water (at 58°C), exceeded 80 kW and 190 kW respectively for over 7,000 hours per year.

Fig 14 CHP Installation

System Economics

The CHP units operate for 17 hours per day. The cost savings resulted in a payback period of about 3.7 years. The total CEM package shows a net saving to the hospital over the 10 year contract, with the added benefit of CHP installation ownership being transferred free of charge to the hospital in 1995. The reliability of the CHP units has been excellent, with an availability of over 90% having been achieved over the past six years. The existing hospital standby generator sets are run for six hours each month on full load, whilst the CHP units are undergoing routine maintenance.

Case Study 4: Greaves Hall Hospital, Southport

Site

Greaves Hall Hospital is a Psychiatric Services Unit located on a 95 acre rural site near Southport. The heating, lighting and hot water required by the 580 patients and staff resulted in an energy bill of about 2180,000 per year.

The existing steam raising plant consisted of four 2,840 kWth dual fuel boilers (gas and oil). Space heating and hot water is provided by steam calorifiers. Steam is also utilised in the hospital laundry.

CHP Installation

The site had a base electrical load of 140 kW with a maximum demand of 335 kW. After consultation, the Health Authority installed a 72 kWe CPS gas-fired unit based on a Ford 6-cylinder engine. The unit supplies the domestic hot water system with 130 kW of recovered heat, with a gas input equivalent to 275 kW.

In the event of grid supply failure, the CHP unit shuts down automatically and the existing standby power system starts up. The CHP unit and standby power generating sets are interlocked to prevent simultaneous operation. The CHP unit was intended to run for 17 hours per day, 7 days per week (i.e. 6,188 hours per year) with an anticipated availability of 90% giving a projected run-time of 5,569 hours per year.

System Economics

Since installation in August 1989, the CHP unit has been running to specification and averaging in excess of 90% availability. Based on 90% availability and 75% efficiency of the existing boiler, current savings are estimated to be 214,368 per year in gas and electricity costs. In addition, further savings in Maximum Demand (MD) tariff charges of about £1,344 were achieved during the winter of 1989/90. The installed cost of the system was £37,500 giving a simple payback of 2.61 years (excluding MD savings). This compares favourably with the originally estimated payback time of 2.7 years. From 1st April 1990, the hospital changed from an MD tariff to a Seasonal Time of Day (STOD) tariff. It is anticipated that this change will further enhance the economic case for CHP and reduce the payback to less than 2.4 years.

Case Study 5: Calderstones, Blackburn

Site

Calderstones is a psychiatric unit located on a 200 acre site at Whalley, near Blackburn. It has 1000 beds and consists of about 80 buildings, the majority of which are about 90 years old. The installation of a CHP system followed an extensive programme of upgrading the energy system on site (such as by installing cavity wall insulation, draughtproofing, pipeline and roof insulation, Building Energy Management Systems (BEMS) and condensate recovery).

A large centralised boiler house, with high pressure and vacuum steam systems and a domestic hot water (DHW) system distribution network, supplies the site.

CHP Installation

Following a detailed review of options, which included the possible conversion of existing standby generators to CHP operation, it was decided to install a stand-alone gas-fired reciprocating CHP unit from CPS having an output of 185 kWe

(310 kW thermal). The unit is controlled by an on-board computer, which is linked via a modem to a central maintenance computer for the transfer of performance data and status reports for both pre-emptive maintenance checks and diagnostic purposes.

The system has operated since April 1990, with the thermal output being used to heat the cold feed and pumped return from the DHW distribution system. The CHP unit was designed to operate at 100% load for 17 hours a day and the system will automatically modulate its output down to 50% of full load during any periods of unusually low demand. In the event of grid failure, the CHP unit shuts down automatically, with the standby generators providing emergency power.

The CHP system was originally specified on the basis of an availability of 90%, but this has been exceeded with an average availability during 1991/1992 of 97.5%. The high level of availability has been achieved as a result of a detailed examination of the thermal base load prior to specification, together with an excellent standard of maintenance service being provided by the CHP supplier.

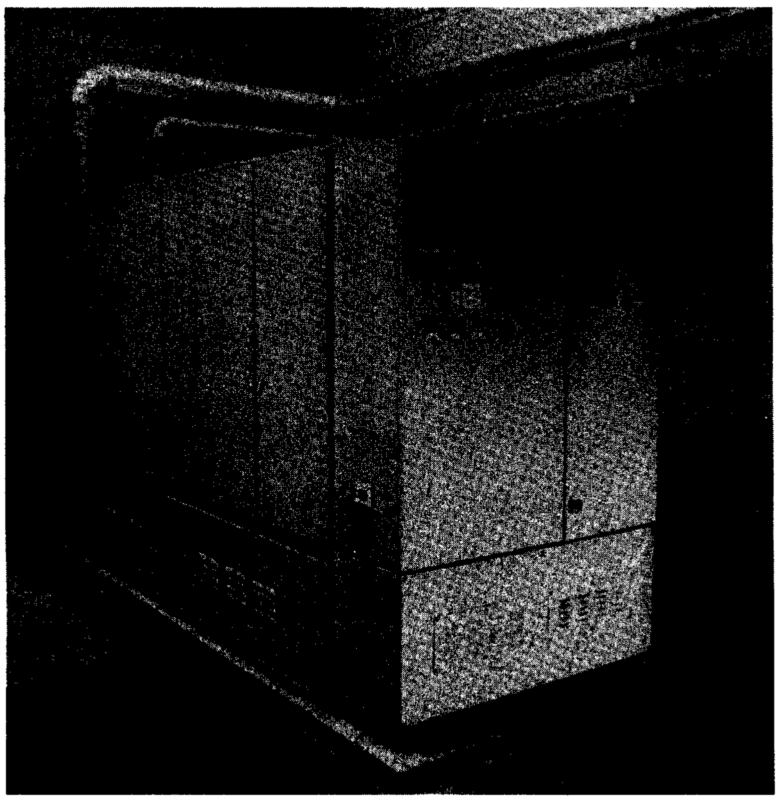

Fig 15 CHP system

System Economics

The installed cost of the CHP system (including a new gas main) was £92,000, which included three year's full parts and labour maintenance. The savings in gas and electricity during 1990 and 1991 have totalled £80,000, and if maintained at the existing level will produce a simple payback of 2.3 years. The CHP installation was financed from the Minor Capital Bridging Fund brokerage scheme operated by the North Western Regional Health Authority, which provided loans to encourage the implementation of energy efficiency schemes.

Case Study 6: Queen Elizabeth Medical Centre, Birmingham [6]

Site

The Queen Elizabeth Medical Centre (QEMC) is South Birmingham Health Authority's largest and most complex hospital site. The site includes the 600 bed Queen Elizabeth Hospital, a 200 bed Maternity Hospital and the University Medical Schools, together with various residences and other health related facilities. All buildings on the 74 acre site share the same steam and electrical services.

CHP Installation

The CHP installation is based on an integrated gas turbine and a clinical waste incinerator, both of which exhaust into a waste heat boiler and economiser. The boiler has been installed within the boiler house, replacing one of the existing 5.86 MW (20 MBtu/hr) coal-fired steam boilers, with the economiser located above it. The 3.6 MWe Centrax dual fuel gas turbine is located in a purpose-built turbine hall adjacent to the boiler house. A new incinerator has been installed in a building on the site of the previous, now obsolete, incinerators. This project was supported financially and monitored for the Energy Efficiency Office (EEO) as an Energy Efficiency Demonstration Project.

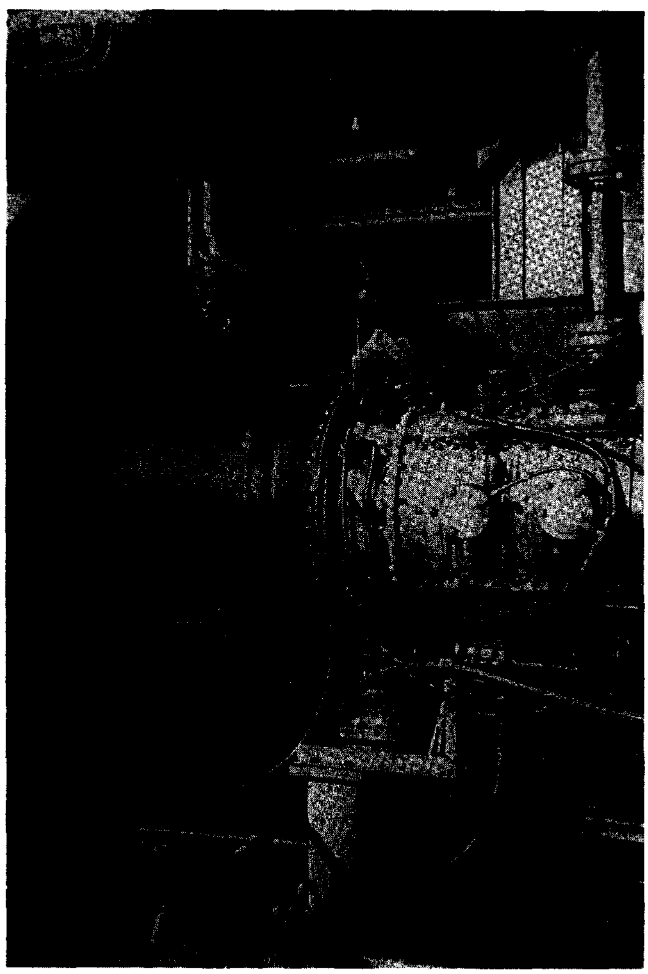

Fig 16 CHP scheme

6 Full details are contained in New Practice Report NP/56, copies of which are available from ETSU's Energy Efficiency Enquiries Bureau (Tel. No: 0235 436747).

System Economics

The CHP installation was originally designed to operate for 24 hours a day for 8 months of the year. The gas turbine was specified to produce 3.6 MWe of electrical power and 5.9 MW of heat in the form of steam at 7 bar. The incinerator was specified with a burning capacity of 750 kg/hr, producing another 1.5 MW of heat in the form of steam whilst operating for 8 hours a day. A further 1.7 MW of heat would be recovered by pre-heating boiler feed water in the economiser unit. The target efficiency for the overall CHP conversion was 76%.

The total installation cost was £2.4 million, with a predicted simple payback of 3.9 years and a Benefit Cost Ratio of 7.36.

The actual measured average conversion efficiency during the first full year of operation was 72%, 4% lower than anticipated. Soon after commissioning a number of mechanical problems were encountered, due to oil carbonisation and turbine blade damage resulting from ignitor electrode failure, but these problems have now been resolved. Despite the lower than anticipated conversion efficiency, the originally projected payback is still expected to be achieved due to the considerably improved income from clinical waste incineration.

Case Study 7: Leeds General Infirmary

Site

In 1970 the DHSS decided large-scale CHP should be evaluated for use throughout the Health Service, and in 1972 approved a scheme for it to be included in the plans for the rebuild of the largely Victorian Leeds General Infirmary, eventually to be a 1,200 bed unit, and the associated Leeds University Medical School.

The CHP installation was commissioned in 1977 and provided sufficient electrical generation to make the site independent of external supplies.

CHP Installation

The installation consists of five 2 MWe Ruston Diesel 16RK3G dual fuel (diesel/gas) reciprocating engines. Each engine provides I MW of steam to supplement the package boiler installation and 0.8 MW of low pressure hot water (LPHW), originally for the provision of DHW. The overall efficiency was designed to be 63-68%.

The projected electrical load was, and now is, 6 MW during the day falling to 2 MW overnight and at weekends.

System Economics

The severe curtailment of the rebuilding programme meant that the domestic water heating load did not materialise and to counteract this some space heating in the existing hospital was transferred to the LPHW system.

The reliability of the engines was poor and it was necessary to keep one engine running in reserve, because the feeder to the REC was inadequate if a running engine failed.

Oil and gas prices escalated to unpredicted levels, and therefore until 1983 the CHP plant was uneconomic. By 1984 high capacity cables were installed to the REC, and the Electricity Act ensured fair rates when exporting surplus power. This meant the engines

could be run at an economic load at all times, and at the same time oil and gas prices fell. Since then reliability problems have been overcome and more LPHW load found.

Each engine now runs for **3,500** - 4,000 hours per year and the financial benefit is now around £500,000 per year (excluding capital charges).

A recent study has shown that it would be economic to replace the diesel/gas engines with gas turbines, mainly due to the resulting reduction in labour costs, both in their operation and maintenance.

Case Study 8: A geriatric hospital

Site

The geriatric hospital is a 95 bed hospital, with a natural gas-fired LPHW boiler plant installed in a central boiler house providing heating and hot water services to all areas of the hospital. Annual energy consumption is approximately 11,000 GJ (10,400 GJ of natural gas and 600 GJ of imported electricity). The performance indicator (PI) is in the order of 70 GJ/100 m^3.

CHP Installation

In 1987 a **45** kWe CHP unit was installed in the central boiler house, in parallel with the existing boilers.

Initially, the installation did not achieve optimum performance for the following reasons:

- The CHP unit was connected into a space-heating system which, under adverse weather conditions, could not provide acceptable temperatures in many of the site's perimeter buildings.
- An adequate heat sink was not available. One reason was that part of the DHW system retained heat exchange coils originally designed for steam operation.
- The CHP unit was piped up in such a way that some return water bypassed it and went straight to the boilers.
- An ineffective control system was installed which tended to be manually overridden especially when complaints of under heating were received. This resulted in the CHP unit frequently shutting down.

Remedial Work

The following remedial work has been carried out:

- Modifications have taken place to improve the heating and DHW distribution.
- Boiler house pipework has been modified and the CHP unit now pre-heats the boiler return.
- The controls have been improved to ensure that use of the CHP unit is given priority status.

Lessons Learnt

From experiences at this geriatric hospital, several valuable lessons have been learnt which will be of use to other hospitals contemplating installation of CHP.

- 'The thermal load of the hospital should have been accurately assessed before installation of the CHP system.

- A detailed review of the existing heating and DHW systems should have been undertaken and their poor performance remedied before a CHP system was selected.
- The CHP unit should have been correctly piped up at installation.
- An integrated control system for the boilers and CHP unit should have been installed.

Case Study 9: Conversion of standby generators

Site

A 400 bed District General Hospital was originally serviced by four steam boilers, but these were replaced by LPHW boilers in 1979. Following analysis of the 1987/88 energy consumption figures, on-site CHP was identified as a viable option. Electricity bills showed typical monthly maximum demands of 410 kW in summer months, and up to 590 kW in winter months. The period of maximum demand was found to occur between 9am and 1pm, and after 6pm electrical demand was found to fall to about 290-330 kW. The site heating and hot water demand was found to vary from only 240 kW in summer months up to 1,770 kW during the winter.

CHP Installation

Payback calculations suggested that the optimum size of CHP unit was 400 kWe, which would have a thermal output of about 750 kW. The Health Authority had recently obtained a 400 kVA generator, believed to be 20 years old, for standby use and so it was decided to convert this set to CHP operation.

The conversion was undertaken and the diesel engine set was installed with a heat store to permit restricted summer-time operation. It was necessary to install an interconnector to the existing 450 kVA standby generator, because both sets were connected to feed the essential service bus-bars and it was essential that they should not run simultaneously.

System Economics

The total cost of the conversion and installation was £160,000, equivalent to £400/kWe. Annual cost savings of £57,000 were anticipated, giving a predicted simple payback period of just under 3 years. A number of engine problems were encountered during commissioning and complete power black-outs were experienced with loss of the mains supply, CHP unit and standby generator. This fault was traced to poor voltage regulation on the REC supply tripping both the CHP unit and the standby generator, and was remedied. Thereafter, the plant performed reasonably well until late 1990 when a fire in the main incomer occurred (not caused by the CHP unit). Although the fire did not spread to the CHP installation, it was necessary to take it out of service as a result of temporary financial constraints.

APPENDIX 1

DETAILED DESIGN AND PLANT SPECIFICATION

Having determined the main operational parameters in the initial feasibility study, a more detailed design exercise should be undertaken to optimise the savings and to ensure that the new plant is integrated satisfactorily with existing hospital electrical and other building services. The following aspects require careful consideration during the detailed design stage:

- type of CHP system (e.g. diesel/gas engines, gas turbine);
- environmental considerations (such as emissions, noise, vibration);
- number and size of CHP units to be installed;
- the possible merits of exporting electrical power to the grid or other sites:
- the use of the CHP system for 'load-lopping' (i.e. to reduce Maximum Demand (MD) or high Seasonal Time of Day (STOD) tariffs) and the implications in terms of possible 'heat-dumping';
- electrical considerations (such as interfacing with hospital electrical system, grid supply, safety, standby);
- controls and instrumentation;
- accurate capital cost and operational saving estimates.

The following sections examine the above issues in greater detail.

A1.1 CHP System Type Specification

The type of CHP system specified will be dependent upon:

- maximum electrical power output required;
- the thermal heat to electrical power ratio;
- fuel types and costs;
- grade (i.e. temperature) of heat required;
- utilisation and availability;
- maintenance requirements and cost;
- environmental consideration (such as exhaust emissions and noise).

Power Output:
The electrical and thermal load duration profiles will enable the maximum required power output to be determined. The ratio between the heat output and electrical output (heat: power ratio) should also be determined under all load conditions, since different types of CHP system produce different ratios. Supplementary firing or use of the exhaust gases should be considered for large CHP installations (i.e. units with an output of over 500 kWe). Part load operation and steam injection to gas turbines can vary the heat to power ratio.

Fuel Type and Cost:
Fuel type is largely dependent on the type of CHP system selected. However, fuel cost is of fundamental importance when considering overall system economics (refer to Section 6 'Economics and Financing'). Of particular importance to hospitals are issues associated with security of supply. If the CHP system is also being used as standby to supply emergency electrical power, a 'storable' fuel (i.e. fuel oil or liquefied petroleum gases (LPG)) should be used to satisfy Department of Health guidelines on local fuel storage/supply.

Design Service Hours:
The design service hours are the number of hours per year that the CHP system **is** designed to be available for operation (after allowing for maintenance down time, shutdown during low import tariff periods, etc).

Utilisation:
Utilisation is the percentage ratio of design service hours per year to the total hours available in a year (i.e. 8,760 hours). For example, a unit designed to operate for 17 hours per day, less 5 hours per month routine maintenance, would operate for 6,145 hours/year. This would give a planned utilisation of 70%.

Availability:
Availability is the term used to describe the percentage ratio of the. actual running hours in a year to the total number of design service hours per annum. Steam turbines and gas turbines have the highest availability values, typically over 95%, with gas engines and diesel engines generally having somewhat lower levels of availability, typically over **90%.**(Typical values are based on the results from independent monitoring of a number of systems carried out on behalf of the Energy Efficiency Office (EEO).) Predicted availability is of considerable importance for systems designed to operate continuously, since the economic case can be seriously affected if the plant fails to achieve the anticipated availability in practice. An availability factor **is** used to enable the effects of unplanned stoppages to be assessed. In the example in (iv) above, a system having **6,145** design service hours and a 90% predicted availability should expect to achieve actual run hours per year of at least 5,530 hours. Many CHP manufacturers and suppliers will provide availability guarantees, offering compensation if the hours are not achieved.

Maintenance:
Maintenance requirements and cost vary depending on the type and size of CHP system specified. Actual maintenance costs will depend upon the location, size and type of the system, as well as in-house resources.

It is essential that life cycle maintenance costs be carefully established using information provided by the CHP manufacturer. The life cycle costs should include routine service and lubrication costs, as well as major overhaul costs, all on an annual basis.

A1.2 Environmental Considerations

CHP is one of the most effective technologies for combating the problems associated with global warming. A significant reduction in the emission of C02 and other greenhouse gases can be achieved by on-site electricity generation and heat recovery.

However, there are three major environmental issues to be considered when specifying a CHP plant:

- exhaust gas emissions;
- noise and vibration;
- disposal of used lubricating oil (from reciprocating engines).

Exhaust Gas Emissions:
Exhaust gas emissions from CHP systems contain some toxic components which can have a harmful effect on the environment. The fuel most widely used for CHP **is** natural gas, and the main toxic emissions resulting from its use are nitrogen oxides (NOx). Other harmful emissions from CHP plant include carbon monoxide, sulphur dioxide, unburnt hydrocarbons and particulates depending on fuel type.

NOx emissions can be limited by:

- active reduction of NOx formation through modified engine design and operation;
- the passive elimination of NOx from the exhaust gases (i.e. the use of catalytic converters).

Both of the above methods reduce both the efficiency and capacity of the CHP unit. The advice of the CHP unit manufacturer should be sought to determine the anticipated NOx emissions for the particular application, in order to ensure satisfactory operation and compliance with the Clean Air Act 1983 for plants having a net thermal input (i.e. fuel burning rate at maximum continuous rating multiplied by the net calorific value (CV) of the fuel) of less than 20 MW.

Sulphur dioxide emissions from CHP systems generally fall well below the statutory requirements. The sulphur content of natural gas is very low, but if biogas or landfill gas is used the sulphur content can be considerably higher. Engine manufacturers usually impose a limit on the sulphur content of the gas to be used, and this should be taken into account in order not to jeopardise the warranty. The sulphur content of diesel fuel is generally low enough not to cause a problem.

If the CHP engine is correctly operated and maintained, the quantities of carbon monoxide and unburnt hydrocarbons emitted should be below current legal limits. Proposed European legislation will reduce the permissible emission levels; however the use of oxidising catalytic converters will enable any currently proposed emission control regulations to be achieved.

If the exhaust gas temperature is to be reduced to below the dew point in the exhaust gas heat exchanger, special precautions should be taken. This is to ensure that corrosion does not take place as a result of the formation of acids. It is recommended that condensing installations are not installed other than on gas-fired plant. The use of stainless steel or other corrosion resistant materials, and/or cleaning of the fuel prior to combustion, will reduce problems associated with corrosion.

Very large CHP schemes having a net thermal input exceeding 20 MW will have to comply with the requirements of the Environmental Protection Act 1990 Part 1 (see the Secretary of State's 'Guidance for Compression ignition engines, 20 - 50 MW net rated thermal input', or the corresponding document for gas turbines based systems). These large schemes require Local Authority authorisation to ensure that any proposed CHP system will satisfy the requirements of the 1990 Act.

Note: Any system with an electrical output of more than 6 MWe (gas turbine), or 8 MWe (reciprocating engine) will probably exceed 20 MW thermal input.

Noise And ***Vibration:***
The attenuation of noise and vibration from CHP units is particularly important at hospital sites. The noise produced by an unattenuated CHP system is usually above 95 dB(A) (higher for gas turbine systems). However, careful design can ensure that sound and vibration levels are reduced to an acceptable level. CHP systems are normally housed within an acoustic enclosure, with the unit supported on an anti-vibration mounting. For smaller systems, a well-built acoustic enclosure alone can reduce the noise level to below 30 dB(A). Large CHP units are generally located within an acoustic enclosure and further enclosed within a soundproofed building. All interconnecting pipework should be flexible, to prevent the transmission of noise and vibration to the building structure.

The noise from gas compressors for gas turbines will also require attenuation. The high frequency noise associated with gas turbines is generally easier to attenuate than the low frequency noise/vibration associated with reciprocating engines.

Disposal Of Used Lubricating Oil:
Degraded lubrication oil from reciprocating engines is hazardous to ground water supplies and arrangements will need to be made for its safe disposal. A number of commercial organisations exist which specialise in removing the oil free of charge, for recycling or for combustion.

A1.3 Size and Number of CHP Units

Determining the size and number of CHP units to install involves a complex process of optimisation.

The electrical load duration curves for the site will provide an indication of the base load and peak load requirements. Instead of installing a single large unit, consideration should be given to the installation of several smaller units, which adds flexibility and enables advantage to be taken of the modular design of some packaged CHP units. Furthermore, in the event of the breakdown, or emergency or routine maintenance of any one unit, power will still be available. Several small units can also be used to match the heat and/or electrical loads more closely.

The main disadvantages of several smaller units are that control complexity is increased, specific investment costs are normally higher and, except when running at full power, the electrical efficiency is lower. In addition, in emergency standby use, multiple units are more difficult to control and greater care should be taken to prevent instability. The effect of installing two CHP units each with a thermal output of 200 kW is illustrated in Fig 8 (Page 22), where Unit 1 will operate for 6,000 hours per year at full load and for a further 2,000 hours at part load and Unit 2 would operate for 3,000 hours at full load and 1,500 hours at part load. The remaining load would be met by boilers.

Part load operation requires a modulating control system and results in reduced electrical efficiency. Gas turbine efficiency falls off dramatically below 80% of full load power. Full load operation is always preferable, although intermittent CHP operation to achieve full load running should be avoided, since rapid on/off cycling of the plant increases wear, starting costs (i.e. poor performance whilst warming up) and emissions.

Choosing a CHP system which is too small implies that savings may be lost. However, it is considered more prudent to undersize rather than risk oversizing a CHP system, because it is always preferable to run a system under full load for a longer period, instead of operating a system for extended periods at part load or repeatedly cycling it on and off. A second CHP unit can be installed later, once the savings, performance and loading of the first unit have been established. A detailed technical/economic appraisal of the selected system should be carried out (preferably by an independent expert) to ensure that the design has been optimised correctly in terms of type, size and number of CHP units. The financial option appraisal techniques summarised in Section 6 should also be used to determine the relative merits of any proposed options.

A1.4 CHP Import and Export of Power

CHP systems can be sized higher than the base load requirement and export part of the electricity they produce to the grid, for part or all of the time. The economic case for export critically depends on the buy-in and buy-back arrangements with the local Regional Electricity Company (REC).

A number of hospitals export electricity for part of the day only (i.e. when buy-back tariffs are high), and import at times when the buy-in tariff is lower than the marginal cost to generate using the CHP system. Large schemes should also consider supplying directly to the Pool, operated by the National Grid Company (NGC) to provide a market for the sale and purchase of electricity by large electricity producers and consumers.

Buy-in tariffs based on maximum demand (MD) charges are generally not very attractive to CHP users, because if the CHP system is temporarily unavailable for any reason (e.g. plant failure, maintenance, etc) an MD charge may be applied, at a high rate, for a period of a whole month or even longer. Normally, if available, Seasonal Time of Day (STOD) tariffs appear to offer many CHP users the best option. Wherever electricity is to be 'exported', the resale or 'buy-back' tariff quoted by the REC will normally be of a multi-rate form, specifying unit electricity prices which vary throughout the day and from month-to-month.

To evaluate fully the possible financial benefits of power export, and the various tariff options now available, hourly and daily generation and demand profiles for each month need to be produced. A number of organisations have developed sophisticated computer software to enable this task to be undertaken quickly and accurately.

It should be noted that the generation of electricity for export requires careful consideration, since the benefits may be non existent, or at best only marginal, at certain times of the day. Conversely, consideration should also be given to using the CHP system for 'peak load lopping' to reduce costs during very high tariff periods, even if this results in having to 'dump' heat from the system at times when the thermal load is low.

For very large CHP installations with substantial electrical export, the hospital may be required to obtain a 'Second Tier Supply Licence'. Guidance regarding licensing requirements can be obtained from the Office of Electricity Regulation (OFFER) (see Appendix 4 for addresses).

For sites which currently exceed 1 MW of electrical load, Contract Supply Tariffs will apply, even if the output of the CHP system reduces the normal load to below 1 MW (i.e. according to OFFER a 1 MW site is always a 1 MW site despite the introduction of CHP). Rates for export of electricity from a site over 1 MW are available from the REC. In April 1994 the franchise limit will be reduced to 100 kW and is to be removed altogether in April 1998.

A1.5 Controls and Instrumentation

Most CHP systems are supplied with the control system and other associated instrumentation already installed. The installation generally comprises microprocessor-based systems which provide control, fault checking and diagnostics, often with remote communications facilities (i.e. modem link) for alarm handling. The level of monitoring possible by microprocessor-based systems enables maintenance requirements to be very accurately predicted and optimised. This monitoring largely accounts for the improvements in availability achieved by second generation CHP systems, because now the diagnostic systems are able to pin-point possible problems (such as low oil level, low water flow rate, increased vibration), so that remedial action can be taken before plant failure occurs.

To provide safe and efficient operation of the system the following sensors should be provided as a minimum:

- flow switches in flow and return pipework, and interlocks with heating system pumps;
- control and limit thermostats;
- low engine oil pressure gauge;
- low gas pressure gauge - gas fuelled engine;
- high gas pressure gauge - gas fuelled engine;
- overspeed sensor;
- low speed protection;
- electrical power overload.

In order to evaluate the performance of the **CHP** system, it will be necessary to monitor the whole plant. The minimum level of instrumentation is:

- electricity generated meter;
- hours run meter;
- fuel consumption meter;
- heat meter.

In addition to any local displays, it may be necessary to provide outputs from all monitored parameters as digital **4** - 20 mA outputs or volt-free contacts as appropriate, on a terminal rail in a separate panel for connection to existing or planned hospital energy management systems.

A1.5.1 Electrical Mains Safety Monitoring G59/1

All CHP systems and controls must comply with the Electricity Association Engineering Recommendation G59/1, which sets out the conditions to be met by a generator when connected to the grid.

The main stipulations of G59/1 are that the generator must be isolated from the grid within 0.5 seconds under conditions that include:

- the failure **of** one or more phases in the distribution network;
- the failure of the **REC** supply.

G59/1 also stipulates that the control equipment must be fitted with an automatic trip or alarm that will indicate if the power supply to the controls fails, to ensure that the equipment **is** fail-safe.

APPENDIX 2

THE CONVERSION OF EXISTING STANDBY GENERATORS TO CHP OPERATION

Most hospital sites have standby generating plant which operates very infrequently. The potential use of this plant for CHP operation may appear attractive, but conversion involves adding heat recovery to an existing engine and upgrading the control system to permit continuous operation, in parallel with the mains supply. In many cases standby generators are not designed for continuous operation and therefore, in order to ensure that continuous running will be reliable, a major engine overhaul and modification may also be necessary.

Standby generators should comply with Health Technical Memorandum HTM2011, which requires that standby generation must be the primary function of such plant, which affects conversion. HTM2011 suggests that single standby units are the most convenient and economic arrangement, and that where more than one unit is installed, each unit should serve discrete parts of the essential load.

The following section describes the potential benefits and problems of converting standby generators to CHP operation, and presents the main issues which must be examined if such conversion is considered.

A2.1 What Does Standby Set Conversion Involve?

The first step in considering the conversion of a standby set should be to consult the equipment manufacturer or supplier to ensure that it is possible to carry out such a conversion. The general requirements and constraints associated with the conversion of standby plant are described below.

A2.1.1 Addition of Heat Recovery

To convert standby sets to CHP operation, the installation of engine jacket and exhaust gas heat exchangers is required. Water is circulated through these heat exchangers in series, reaching an outlet temperature of 80 - 90°C, and is then fed into the hospital heating or DHW system. It is essential that these heat exchangers are adequately sized with due allowance for fouling; typically they should be oversized by 10%. The primary function of this cooling system is to maintain the engine at a reasonable working temperature, and it is critical that there is sufficient flow of coolant through the engine. It will also be necessary to incorporate over-temperature protection, to avoid outlet temperatures exceeding 98°C.

It is vital to ensure that, if the converted standby generator is incorporated into an existing hospital heating system, there will be sufficient water flow through the engine at all times. This will almost certainly require an additional set of pumps, and it will also be necessary to install isolating and flow regulation valves to permit commissioning and maintenance.

The heat recovery heat exchangers will normally be of the shell and tube type, and stainless steel should be used for the exhaust gas heat exchanger to reduce the risk of corrosion. Fin tube heat exchangers may be considered for exhaust gas heat recovery; they are expected to have longer services lives than shell and tube heat exchangers, but give poorer sound reduction and have lower efficiencies. On a gas-fired engine, the use of a condensing heat exchanger could be considered: this would give greater heat recovery, but at a higher cost.

A2.1.2 Electrical Installation

Existing standby generators are synchronous, but if a generator is purchased with the intention of converting it, its type should be checked.

Commonly, standby generator installations are intended to supply a small number of essential loads via an automatic change-over contactor. These essential loads are supplied via dedicated fuse-boards, with no facility for changing the loads selected. In a simple conversion to CHP operation the automatic change-over system could be reversed, i.e. the normal supply to the loads would be derived from the generator with automatic change-over to the mains in the event of a generator failure. Thus if it were decided to convert the generator, and maintain the supply to the existing loads only, the amount of electrical system modifications would be minimal. The existing electrical load for such a CHP unit would, however, be fixed and might not utilise the maximum output from the generator. In addition it may be very difficult to determine how many hours per year these loads require electricity.

A2.1.3 Thermal And Electrical Outputs

Heat output from converted standby generators will be useful for low pressure hot water (LPHW) and domestic hot water (DHW) systems only. For higher temperature systems (medium pressure hot water (MPHW) and steam) purpose designed high temperature CHP units should be used.

Useful energy outputs from a standby generator engine converted to CHP use at LPHW temperatures, may be expected to be as follows:

- electricity produced 30 - 32% of fuel input;
- useful heat from jacket heat exchanger 22 - 30% of fuel input;
- useful heat from exhaust heat exchanger 20 - 25% of fuel input.

Standby sets are typically highly rated for intermittent use, and in continuous operation the electrical output may be expected to be about 10% less than the standby rating.

A2.1.4 Condition of Engine

The reliability of converted standby generators will be greatly affected by the condition of the engine. Engines may be perhaps 15 or 20 years old, with less than 500 running hours and while this might suggest that little or no wear has occurred, and the engine may appear to be in a ‘nearly-new’ condition, it may not be the case. For example, acidification of antifreeze may have caused considerable internal corrosion. Additionally, in an engine that has been standing idle for long periods of time, lubrication of components may have been poor or non-existent and, on startup, excessive wear of these components may have occurred.

Extended running tests should be carried out with sets considered for conversion, and if there is any concern about the condition of the engine it should be thoroughly examined and tested by an expert. The cost of overhauling the engine prior to conversion must, of course, be added to the overall capital cost when carrying out the financial appraisal; however, it may save money in the long term.

There is little statistical information available on technical problems associated with CHP installations, although it has been found that some failures have been caused by the use of engines in applications for which they had not been designed, in particular by using engines which were not suitable for continuous operation. This point is of particular relevance when considering standby set conversion. Since standby sets are intended for light duty, their conversion may require the installation of larger sumps to reduce the frequency of oil changes, increased oil storage capacity and the addition of autofill systems.

In general, standby sets with engines based on automotive designs are not recommended for conversion to CHP. The most suitable sets are those with engines designed for stationary applications or marine use. Engines with rotational speeds of 1,500 rpm or less may be

suitable for conversion, whereas conversion of engines with higher rotational speeds is not recommended.

A2.1.5 Provision of Electrical Supply

Security of supply in a hospital is vital. To allow for routine maintenance, an existing standby generator should be considered for conversion only if all essential loads can be met without it being operational. Therefore, where standby power **is** provided from a single unit, its conversion to CHP use cannot be considered. The amount of standby power required will depend on the extent of the segregated circuits, and on the loads supplied from them.

If the converted CHP plant is also required to supply emergency electrical power in the event of a mains failure, then the following switchgear will be required:/

- automatic means of isolation to disconnect the site electrical network from the grid;
- automatic means of isolation to disconnect non-essential circuits from the generator;
- a contactor to connect the generator neutral to earth.

In addition to these switchgear requirements, an automatic battery-powered generator starting system will be required.

A2.1.6 Conversion of Diesel Engines to Gas

Some diesel engines may be converted to run on gas, but this requires a significant derating. For conversion, it is necessary to: reduce the compression ratio by changing or machining pistons; modify cylinder heads for the installation of spark plugs in place of the diesel injectors; create a distributor drive for the ignition system; and install an engine control system. There are expert contractors who will carry out such work, but they are normally engine specialists and are not usually capable of undertaking the electrical work necessary for converting a diesel standby generator to a gas-fired CHP system. In addition, these contractors will generally only convert particular types of engines, and the maximum size of engine is likely to be restricted to about 240 kWe. **It** should be noted that not all diesel engines are suitable for conversion to gas - consult the engine manufacturer or supplier.

A2.2 Conversion of Existing Standby Generators - Summary

By 1991 about 15 standby generators at 9 hospital sites had been converted to CHP use. These conversions were a mixture of used sets bought in specifically to convert, and existing sets converted for the site where they were originally installed. Results have been mixed, with good results at some sites, but particular problems at others, such as:

- considerably lower than expected heat recovery from the engines.
- conversions taking longer than was forecast, and exceeding cost estimates.
- low annual running hours on some sites, due to poor reliability of engines.
- higher than expected maintenance costs.
- complete blackout at one site: this was eventually traced to poor voltage regulation on the area board, tripping both the CHP set and the standby generator.

Serious consideration should be given to the conversion of existing hospital standby generators to CHP use only if an affirmative answer can be provided to all the following questions:

1 Is the heating system LPHW, rather than MPHW or steam?

2 Does the heating load duration curve give high expected annual running hours (at least 4,500 per year)?

3 Is the standby set adjacent to the supply points for both heating and electrical connections?

4 Are the heating and electrical connection points capable of accepting the full outputs of the CHP unit?

5 Is the engine speed 1,500 rpm or less?

6 Is there adequate electrical standby provision at times when the CHP unit will be out of service for routine maintenance?

7 Is the engine in excellent mechanical condition?

8 Is the generator synchronous?

9 Does the conversion meet the criteria set by the hospitals for financial return on investment?

10 Is the hospital prepared to operate the plant on a non-storable fuel (e.g. natural gas)?

Conversion of existing standby generators requires careful consideration. Very few sites will have plant that is suitable for conversion, when all the above criteria are considered. The economic case may also be questionable if all costs associated with site work, safety, noise attenuation, diesel-to-gas conversion, control and instrumentation and so on are evaluated accurately. The constraints imposed by Health Technical Memorandum HTM 2011 could also significantly reduce the applicability of conversion.

APPENDIX 3

RELEVANT ACTS OF PARLIAMENT, STATUTORY REGULATIONS AND GUIDANCE NOTES

The following sections review the various Acts of Parliament, Statutory Regulations and Guidance Notes which will have an affect on the installation of CHP in the Health Sector.

A3.1 Acts of Parliament

England, Scotland & Wales	*Equivalent Northern Ireland Legislation*
Fire Precaution Act 1971	Fire Services (NI) Order 1984
Health and Safety at Work Act 1974	Health and Safety at Work Order (NI) Order 1978
Control of Pollution Act 1974	
Electricity Act 1989	Electricity (NI) Order 1991
Environmental Protection Act 1990	NI Equivalent under discussion
Clean Air Act 1956	Clean Air (NI) Order 1981
Factories Act 1961	Factories Act (NI) 1965

A3.2 Statutory Regulations

England, Scotland & Wales	*Equivalent Northern Ireland Legislation*
Electricity at Work Regulations 1989	Electricity at Work Regulations (NI) 1991
Electricity Supply Regulations 1988	Electricity Supply Regulations (NI) 1991
Gas Safety Regulations 1972	
Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (NI) 1986
Safety Signs Regulations 1980	Safety Signs Regulations (NI) 1982
Control of Substances Hazardous to Health 1988	Control of Substances Hazardous to Health (NI) 1990

A3.3 Guidance Notes and Related Documentation

The following list is an indication of the more important references and does not preclude the use of numerous available British Standards where relevant.

- Institution of Electrical Engineers (IEE) Wiring Regulations for Electrical Installations (16th Edition)
- The Distribution Code of the Public Electricity Suppliers of England and Wales 1990
- Electricity Association Technical Documents:

G59/1	Recommendations for the Connection of Embedded Generating Plant to the Regional Electrical Company's Distribution Systems
G5/3	Limits of Harmonics in the UK Electricity Supply System
G 1212	National Code of Practice on the Application of Protective Multiple Earthing to Low Voltage Networks

P13/1	Electric Motors Starting Conditions
ETR 113	Guidance Notes on the Protection of Private Generating Sets up to 5 MW for Operation in Parallel with Electricity Company's Distribution Networks

- Health and Safety Executive Documents:

GS27	Protection against Electric Shock
GS47	Safety of Electrical Distribution Systems on Factory Premises
PM32	The Safe Use of Portable Electrical Appliances
PM53	Emergency Private Generation Electricity Safety
HS(G)13	Electrical Testing: Safety in Electrical Testing
HS(G)47	Avoiding Danger from Underground Services
HS(G)50	Storage of Flammable Liquid in Liquid Tanks (up to 10,000 m3 capacity)
HS(G)52	Storage of Flammable Liquid in Liquid Tanks (exceeding 10,000 m3 capacity)
HS(G)56	Noise at Work: Noise Assessment, Information and Control
HS(R)23	A Guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985
HS(R)25	Memorandum of Guidance on the Electricity at Work Regulations 1989

- British Gas Publications and Related British Standards

IM/2	Purging Procedures for Non Domestic Gas Installations 1975
IM/5	Soundness Testing Procedures for Industrial and Commercial Gas Installations 1979
IM/16	Guidance Notes on the Installation of Gas Pipework, Boosters and Compressors in Customer's Premises 1985
IM/17	Code of Practice for Natural Gas Fuelled Spark Ignition and Dual Fuel Engines

In addition, gas pipework must conform to BS21, BS1287 and BS1965, and flexible gas pipework must conform to BS6501 Part 1.

- Health Technical Memoranda

HTM2007	Electrical Services: Supply and Distribution
HTM2011	Emergency Electrical Services
HTM2020	Electrical Safety Code of Low Voltage Installations
HTM2021	Electrical Safety Code for High Voltage Installations

A3.4 Electricity Regulation in England and Wales

The current structure of the Electricity Supply Industry (ESI) for England and Wales came into effect on 1 April 1990, in accordance with the Electricity Act 1989 which governs the activities of the industry. The evaluation of CHP schemes other than the simplest requires an understanding of the ESI's structure and regulatory system.

The basic structure of the ESI comprises generation, transmission and distribution. The regulatory body is the Office of Electricity Regulation (OFFER), headed by the Director General of Electricity Supply (DGES).

'Generation comprises three main companies created by re-grouping the previously state-owned power stations, and independent generation companies. The main generators are Nuclear Electric (which remains in public ownership), National Power and Powergen. Independent generators are new companies set up as commercial ventures in the normal way.

Transmission is via the national grid system which receives the outputs from the generators and delivers electricity to the twelve distribution regions of England and Wales. The system is operated by the National Grid Company (NGC), which is also responsible for the Scotland/England and France/England links, and the two pumped storage power stations. NGC coordinates the inflow and outflow of electricity in order to meet demand, ensure lowest cost to consumers and maintain transmission system technical integrity.

Distribution is effected by twelve companies created from, and operating over, the same areas as the previous regional electricity boards; originally termed public electricity supply companies (PES) they are now usually referred to as regional electricity companies (RECs). Each REC is responsible for the reception of electricity from the grid, and distribution and supply to individual consumers in its area. The twelve RECs jointly own NGC. Each REC may have its own or part-owned independent generation company or companies, but may not produce more than about 15% of its requirements by this means.

RECs buy electricity from the generators, pay the NGC for use of the transmission system and add the cost of distribution and supply as the basic framework for building up the price charged to the consumer. The 'wholesale' price, i.e. the price paid to the generators, is determined by the Pool system, which is administered by NGC. By 10.00 a.m. each day, every generator must state a unit price for each half-hour of the following day, for each available generating plant. The NGC will assess the offers against the next day's forecast demand profile, select from them according to cost (subject to technical constraints), and by *3.00* p.m. publish the desired schedule. In order **to** stimulate competition, there is considerable freedom for the parties which comprise the ESI and the consumers, subject to licensing requirements and the scrutiny of OFFER.

The Secretary of State for Trade and Industry must be notified of all generating plant having a capacity greater than 200 kWe. It is mandatory that all electricity generating plant be licensed, or be exempt from licensing. Applications for licences are made to OFFER, which is also responsible for ensuring that the terms are complied with. Licences/exemptions are required for generation, transmission and supply; only the first and third are applicable to CHP operators within the scope of this Guide, and are conveniently defined by quoting the relevant exemption conditions:

- A generation licence is not required for plant with total net output below 10 MWe (nor above this providing it is all used on site).
- A supply licence is not required if 51% or more of the electricity produced is used on site and the balance is exported to a licensee (e.g. the local REC) OR the entire output is exported to a licensee OR less than 500 kWe is exported to consumers direct.

This is the barest summary of the conditions laid down in Statutory Instrument (SI) 1990 No. 193 issued under the terms of the Electricity Act 1989, and they may well be modified or extended subsequently. Potential CHP plant operators should consult their regional OFFER office for licence and exemption information specific to their circumstances.

The Non-Fossil Fuel Obligation (NFFO) is a requirement laid on each REC to secure a specific amount of electricity from nuclear and renewable energy sources. This means that a CHP plant based on a range of 'waste' fuels (e.g. biogas, municipal refuse) can obtain a much higher price for exported electricity, to the extent that condensing steam turbines may be profitable. These enhanced prices are financed by a levy on all electricity sold by licensed suppliers. (NOTE - CHP operators holding a supply licence because they export more than 49% of their electricity production are liable for the levy on the proportion used on site.) The contract is between the CHP operator and the local REC, and application in the first instance should be to the Non-Fossil Purchasing Agency Ltd (NFPA) which is owned by, and acts as an agent for, the RECs collectively.

The technical standards and integrity of the transmission and distribution networks are governed by the Grid Code and Distribution Code respectively. These codes are observed and enforced by the NGC and RECs, who will charge for any reinforcement to the local and national networks which may be needed in order to accept power exported from CHP. The size and cost of such modifications range from nil to very substantial depending on the capacity of the network(s) in the vicinity of the CHP site, and potential generators should contact their local REC to discuss the implications as soon as the likely size of plant is known.

A3.5 Electricity Regulation in Scotland and Northern Ireland

The Electricity Act 1989 applies in Scotland as well as in England and Wales. The equivalent legislation in Northern Ireland is the Electricity (Northern Ireland) Order 1992, SI 1992/231 (NI.1).

The Electricity (Applications for Licences and Extensions of Licences) Regulations 1990 SI No. 192 and the Electricity (Class exemptions from the requirement of a Licence) Order 1990 SI No. 193 also apply in Scotland. Equivalent 'applications' (SR 1992 No. 177) and 'exemptions' (SR 1992 No. 88) rules apply in Northern Ireland.

The Secretary of State for Scotland, in exercise of the powers conferred by Sections 5(1), 6(6), 7 and 10 of the Electricity Act 1989, has granted two licences so far. These licences are held by Scottish Power plc and Scottish Hydro Electric plc, and effectively came into force under the Electricity Act 1989 (Transfer Date) (Scotland) 1990 Order SI No. 197 (s24) on 31 March 1990.

The licences granted in Scotland are unique in that they are composite licences which authorise both companies to generate electricity in Great Britain and transmit, distribute and supply electricity within an authorised area. Copies of the licences for the two Scottish companies are available from HMSO, Volumes 1 & 2 ISBN Nos 0-11-494133-5 and 0-22-4941 17-3, at £8.15 each. The Office of Electricity Regulation (OFFER) in Scotland is headed by the Deputy Director General for Electricity.

Under Article 10 of the Electricity (Northern Ireland) Order 1992, the Economic Development Department has granted four licences for the generation of electricity, and two licences to Northern Ireland Electricity plc, one for the transmission and one for the supply of electricity. These licences came into force on 31 March 1992.

The Office of Electricity Regulation in Northern Ireland (OFFER NI) is headed by the Director General of Electricity Supply for Northern Ireland. It should be noted that the Director General for Electricity has a duty under Section 47 of the Electricity Act 1989 to collect information on the generation, transmission and supply of electricity, including in particular the supply to any premises of heat produced in association with electricity and steam. OFFER are in the process of establishing a CHP database of such activities. A similar duty is placed on Northern Ireland's Director General of Electricity under Article 50 of the Electricity (Northern Ireland) Order 1992.

Throughout the UK, a licence is not required for the generation of electricity if the load is 10 MWe or below. The Electricity (Class Exemptions from the Requirement for a Licence) Order 1990 SI 193 (in Northern Ireland SR 1992 No; 88) sets out the precise terms of the exemptions from the need for a generation licence and a supply licence.

A Scottish hospital which chooses to generate electricity with the intention of selling to a Scottish electricity company should be aware that the companies are under no legal obligation to buy and, in any case, in Scotland there is currently surplus generating capacity. It is theoretically possible under current legislation for a Scottish hospital to generate electricity on one site and, through a Scottish electricity company's distribution system and/or grid, provide the electricity to another hospital. If the load amounts to less than

500 kWe at any one moment, a generating licence is not required but there will be a charge by the electricity company for the use of their distribution system. Any Scottish hospital undertaking such an arrangement would be obliged to generate and supply electricity as demanded by the remote hospital load and follow their load pattern. Scottish hospitals would be required to enter into a 'use of system and connection' agreement with the relevant electricity company, the charges for which would cover the costs of any associated metering and maintenance made necessary by that supply ('use of system' charges will be published annually by both Scottish electricity companies). A similar arrangement to that described above where the remote hospital was a contracted customer, could be legally established, and of course the customer need not be a hospital or hospital but could be any another body, institution, company or individual. It would be possible for a Scottish hospital to supply a customer in the 1 MW and above range providing that the hospital held a Second Tier Licence for that supply.

In Northern Ireland similar rules apply. The 'use of system' arrangements would be made with Northern Ireland Electricity plc, which is obliged to offer the applicant non-discriminatory price regulated terms for connection to, and use of, its system. If the load to be supplied to the contracted party is above 500 kWe, a second tier supply licence is needed.

APPENDIX 4

REFERENCES AND FURTHER INFORMATION

A4.1 References

A4.1.1 General

Available on request from the Energy Efficiency Enquiries Bureau, Energy Technology Support Unit (ETSU), Harwell, Oxfordshire OX11 ORA. Tel No: 0235 436747 Fax No: 0235 432923 :

Good Practice Guide 1:	'Guidance Notes for the Implementation of Small-Scale Packaged Combined Heat and Power'.
Good Practice Guide 3:	'Introduction to Small-Scale Combined Heat and Power'.
Good Practice Guide 30:	'The Efficient Use of Industrial Boiler Plant'.
Good Practice Guide 43:	'Introduction to Large-Scale CHP'.
New Practice Report 41:	'Remote Monitoring of Second Generation Small-Scale CHP Units'

'Learning from experiences with Small-Scale Cogeneration', CADDET Analyses Series No.1, ISBN 90-72647-11-4.

Available on request from the Enquiries Bureau, Building Research Energy Conservation Support Unit (BRECSU), Building Research Establishment, Garston, Watford WD2 7JR. Tel No: 0923 664258 Fax No: 0923 664097 :

Good Practice Guide 27:	'Energy Audit and Survey Guide for Building Financiers and Senior Managers?.
Good Practice Guide 32:	'Condensing Boilers: Applications Manual'

Other publications under the EEO's Best Practice programme, both on general energy efficiency measures in buildings and on energy efficiency in the National Health Service, are also available from BRECSU.

'Saving Energy in the NHS', Audit Commission, HMSO, ISBN 0-11-886049-6.

'Use of private sector capital in the NHS', Department of Health circular EL (89) MB142 October 1989.

'Option Appraisal. A Guide for the NHS', HMSO.

ENCOST WIMS and ENCODE manuals from NHS Estates.

'Contract Energy Management in the Public Sector', EEO, Department of the Environment.

Evans, R. D. 'Environmental and Economic Implication of Small-Scale CHP', Energy and Environment Paper No. 3, ETSU Chief Scientists Group.

'Secretary of State's Guidance - Gas Turbines, 20 - 50 MW net rated thermal input', Environmental Protection Act 1990 Part 1, DOE PG1/4 (91) Feb 1991.

'Secretary of State's Guidance - Compression Ignition Engines, 20 - 50 MW net rated thermal input', Environmental Protection Act 1990 Part 1, DOE PG1/5 (91) Feb 1991.

A4.1.2 Electrical

'Code of Practice for Designers, Installers and Users of Generating Sets', Association of British Generating Set Manufacturers, Technical Memorandum TM3, 1985.

HM Government Energy Act 1983.

Statutory Instrument No. 136 Electricity 1984.

A4.2 British Standards

BS21	Pipe Threads for Pressure Tight Joints.
BS89	Electrical Indicating Instruments.
BS159	Busbars and Busbar Connections.
BS 162	Electrical Power Switchgear & Associated Apparatus.
BS417	Galvanised Mild Steel Cisterns.
BS440	Stationary Batteries for General Electrical Purposes.
BS649	Diesel Engines.
BS764	Automatic change-over contactors.
BS775	Contactors.
BS799	Oil-burning equipment.
BS822	Terminal markings for electrical machinery.
BS 1387	Steel Tubes Suitable for Screwing to BS21.
BS 1649	Guards for shaft couplings.
BS 1710	Identification of pipelines.
BS1965	Pipe fittings for pressure purposes.
BS2613	Electrical performance of rotating machines
BS2709	Electrical performance off semiconductor rectifiers.
BS2771	Electrical equipment for machine tools.
BS 1869	Fuel oil for oil engines.
BS3535	Safety Isolating Transformers.
BS3926	Use and maintenance of engine coolant solutions.
BS3938	Current transformers.
BS3941	Voltage transformers.
BS4553	PVC insulated cables with copper conductors.
BS4959	Corrosion and scale prevention in engine cooling water systems.
BS4999	General requirements for rotating electrical machines.
BS5117	Test methods for corrosion inhibition performance of antifreeze solutions.
BS5467	Armoured cables with thermosetting insulation.
BS5963	Electricity operated automatic gas shutoff valves.
BS6004	PVC insulated cables for switchgear and control gear wiring.
BS6007	Rubber insulated cables.
BS6231	PVC insulated cables for switchgear and control gear wiring.
BS6346	PVC insulated cables for electricity supply.
BS6480	Impregnated paper-insulated cables.
BS6644	Installation of gas-fired boilers 60 kW - 2 MW.

A4.3 Miscellaneous

Codes of Practice (issued by British Standards Institute):

CP1008	Maintenance of electrical switchgear.
CP300	Oil firing.

'1956 Clean Air Act Memorandum on Chimney Heights', Department of the Environment, ISBN 0-11-7613584.

A4.4 Useful Addresses

A4.4.1 Sources of Specialist Advice

Advice on the selection of a specialist consultant can be obtained from:

Association of Consulting Engineers
12 Caxton Place
London SW1H OOL
Tel: 071 222 6557

Energy Systems Trade Association
PO Box 16
Stroud GL5 5EB
Tel: 045 387 3568

Institute of Energy
18 Devonshire Street
Portland Place
London W1N 2AU
Tel: 071 580 7124/6

Combined Heat & Power Association
Third Floor, Grosvenor Gardens House
35/37 Grosvenor Gardens
London SW1W OBS
Tel: 071 828 4077

Chartered Institution of Building
Services Engineers (CIBSE)
222 Balham High Road
Balham
London SW12 9BS
Tel: 081 657 5211

Heating & Ventilating Contractors' Association
Esca House
34 Palace Court
London W2 4JG
Tel: 071 229 2488

A4.4.2 Regulatory Bodies

Advice and information concerning the operation of the Electricity Supply Industry can be obtained from:

Office of Electricity Regulation (OFFER)
Hagley House
Hagley Road
Edgbaston
Birmingham B16 8QG
Tel: 021 456 2100

Office of Electricity Regulation (OFFER) in Scotland
48 St Vincent Street
Glasgow G2 5TS
Tel: 041 248 5917

Office of Electricity Regulation in
Northern Ireland (OFFER NI)
Brookmount Buildings
44-46 Fountain Street
Belfast BT1 5EE
Tel: 0232 31 1575